WORKSHOP PROCEEDINGS

April 26 - 28, 1994, Atlanta, GA

Water Management In Forested Wetlands

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WATER MANAGEMENT IN FORESTED WETLANDS

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Tom Welborn was key in realizing the need for a workshop of this nature and securing the needed funding. Assistance of Region 8 of the US Forest Service was enlished to plan and execute the workshop and publish the proceedings. Appreciation to Bruce Bayle who handled the meeting logistics and coordinated the publication of the proceedings.

Renee Baker did a fine job of organizing and preparing the submitted papers for the proceedings. Assisting her was Neal Mason who ably handled the presentation of the graphics and in all round computer assistance.

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FORWARD

Forested wetlands within the United States provide a variety of functions and values that benefit forested wetland owners, water quality, wildlife, biodiversity, and other societal benefits. The ability to effectively manage forested wetlands and provide for the beneftis listed above has been the focus of protection and management efforts by Federal, state, and local agencies, as well as the landowners themselves.

The continued economic and biological vitality of forested wetlands poses great challenges to private landowners. Extensive information dealing with forested wetlands within the United States has been generated by numerous research institutions, forest industry, and government agencies at all levels. Innovative management options are being employed by private landowners, even as additional research continues.

The WATER MANAGEMETN IN FORESTED WETLANDS WORKSHOP was a cooperative undertaking designed to make available valuable information regarding water management in forested wetlands to policy makers and managers who need this information to effectively manage forested wetlands. The workshop brought together approximately 70 specialists from academia, Federal and state regulatory agencies, timber industry, consulting foresters, and interested individuals to share ideas and research on managing forested wetlands. This project was funded by the US Environmental Protection Agency through an Interagency Agreement with the USDA Forest Service (Agreement Number DW-12-94-5632-01-0).

SOIL SURVEYS AND WATER MANAGEMENT IN FORESTED WETLANDS

FORESTED WETLANDS WORKSHOP
4/26-28/94
ATLANTA

DeWayne Williams
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SOIL SURVEYS

Soil Surveys are an inventory of the kinds of soils that occur in an area. Normally the Soil Conservation Service (SCS) makes and publishes soil surveys by counties. The boundaries of different kinds of soils are located and recorded on aerial photographs at a scale of 1:20,000 or 1:24,000, some are at 1:12,000 or at a larger scale. The Soil Conservation Service makes soil surveys because Congress inacted legislation for investigation of soils in 1895 and transferred the authority to the Soil Conservation in 1935.

Soil surveys differ in degree of detail in addition to scale. They are designed based on anticipated use which has been basically agricultural activities. Because soil surveys have proven to be a useful tool for many different activities, they are often used for activities they are not designed for such as wetland delineations. When activities require detailed information on areas of less than about 3 acres, on-site investigation should be done to insure proper soil interpretations. Many of the older soil surveys contain outdated interpretations; however, updated interpretations are available in the local SCS field office technical guide.

Soil surveys are available on over 90 percent of the private land area. Most counties have a published soil survey and some progress is being made in digitizing. I might add that we have a map called STATSGO which is general in nature and at a scale of 1:250,000. Those of you who have used soil surveys hopefully understand the merits and limitations of soil maps. The composition of map units vary according to map scale, soil patterns, and intensity of use. Inclusions occur in all map units. Many inclusions tend to interpret in a like manner, but some are contrasting. Contrasting inclusions are normally identified by landscape position in the map unit description.

Soil surveys can provide valuable information useful in planning and management of forestlands. Soil properties vary considerably, often over short distances. The kind and arrangement of properties in a soil influences many interpretations and management decisions.

Water movement in a soil depends on many factors, but the kind and amount of clay largely determines the rate and direction of flow. Other factors include depth and kind of cemented pan, depth to rock, texture and arrangement of horizons, and position in the landscape.

Cemented pans are not numerous, but we do have a few. Ortstein, a cemented spodic horizon, occurs in a few soils along the Atlantic coast from North Carolina to Florida. Duripans are extensive in the western U.S., as are petrocalcic and petrogypsic. Don't be alarmed by these terms. They are simply terms for specific kinds of cemented layers in soils. Fragipans are by far the most extensive pan y in forested areas. Many studies have been made, but we still do not have conclusive evidence as to what caused fragipans to occur. The facts are that they do occur and we must contend with them. Fragipans retard the downward movement of water,

restrict root development, and retain very little available water. Soil water tends to accumulate on top of the fragipan and moves laterally to a lower elevation. Roots have a difficult time entering the higher density pan and also tend to turn laterally. The effect is a deep soil acting as if it were a shallow soil. Soils containing fragipans generally have perched water tables above the pan. As a rule, fragipans occur in upland or terrace positions.

The Soil Conservation Service (SCS) has a large data base containing soil properties on some 18,000 soil series. These properties referred to as attributes have varying degrees of reliability. Some are measured, some are derived, and some are estimated based on experience and similar soils. Laboratory samples provide the basic data for the stored attributes. Our soil survey laboratory has collected data on about 15,000 pedons. In addition, we have access to an even larger number available from state agricultural universities.

Attributes of interest to this conference include clay content,bulk density, permeability, reaction, available water capacity, salinity, exchangeable sodium percent, organic matter, erodibility, flooding, ponding, watertables, depth to pans, bedrock, subsidence, drainage class, and climate data.

Clay content is very important. Clay along with organic matter determines the ability of a soil to hold moisture and nutrients. Clay content is directly related to permeability. Other factors are involved, but an increase in clay content generally means a decrease in permeability. Mineralogy tempers this relationship considerably as does the presence of cemented pans.

High bulk densities retard the movement of water and roots. Heavy equipment operating on wet loamy and clayey soils can create a compacted zone of high bulk density near the surface. This results in decreased water infiltration and root development.

Subsidence is a major concern in establishing drainage systems on organic soils. About half of the material to the depth of the lowered water table will be lost during the first three years. This loss is permanent.

SOIL CLASSIFICATION

Soil classification has always been a good vehicle to assist in making soil interpretations. The formative elements provide considerable information about the properties and potential of a soil.

For example, the formative element "aqu" indicates a degree of wetness depending on where it occurs in the taxonomic name.

Taxonomic class - Typic Argiaqualfs the aqu at the suborder level indicates the soil has aquic conditions within 40 cm (16").

Taxonomic class - Aquic Argiudalfs the aqu at the subgroup level indicates the soil has aquic conditions within 75 cm (30")

Another we might touch on is Typic Hydraquents the aqu again indicates the soil has aquic conditions within 40 cm (16"), but the hydr also indicates the soil is saturated most of the time.

Perhaps the issue of vital importance is hydric soils. First of all, a hydric soil does not equal a wetland. All wetlands have hydric soils, but not all hydric soils are wetlands.

Definition of a hydric soil "A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part".

The National Technical Committee for Hydric Soils have developed criteria to select a list of soils from our Soil Interpretations Record database that meet the requirements of the definition.

The list of hydric soils is published in a miscellaneous publication entitled "Hydric Soils of the United States". The last publication was in 1991. Plans are being made to publish an update in late summer of this year. However, the preferred list of hydric soils is the county list which is available in each of our field offices. Most counties in the U.S. have a local field office. SCS state offices can also provide copies of county lists. The county list is preferred because it contains additional information not in the National list. Miscellaneous land types that are hydric and map units that contain only inclusions of hydric soils are added to the county list.

Membership - National Committee for Hydric Soils

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Lists of hydric soils are important for broad planning, but fall short in the realm of direct application. On site examination of a soil is necessary to determine its hydric status. In making lists of hydric soils a soil phase is determined to be hydric or not hydric. In reality some soil phases are in fact both, but is considered hydric for inclusion on the hydric list. For example, a soil may have a water table of 0 to 2 feet. That part of the soil having a O to 1 foot water table is hydric, but that part having a water table of 1 to 2 foot is not hydric. Therefore, it is necessary to make determinations on-site. One further word - hydric soils is only one part of the wetlands triangle. Hydrology and vegetation are required to determine if an area is a wetland

DRAINAGE CLASSES

Seven natural drainage classes are recognized. Drainage classes refer to the degree, frequency, and duration of wet periods. It is the water regime assumed to be present under relatively undisturbed conditions similar to those under which the soil developed. Drainage classes are inferred through observations of landscape position and soil morphology.

The seven natural drainage classes are:

1. Excessively drained
2. Somewhat excessively drained
3. Well drained
4. Moderately well drained
5. Somewhat poorly drained
6. Poorly drained
7. Very poorly drained

We will confine our discussion to the last three for this conference.

VERY POORLY DRAINED - water is removed from the soil so slowly that free water remains at or very near the surface during much of the growing season. Unless artificially drained, mesophytic plants cannot be grown. Most Histisols and long duration ponding are very poorly drained. This group of soils are hydric.

POORLY DRAINED - water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains for long periods. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic plants cannot be grown, unless the soil is artificially drained. The majority of these soils occur on nearly level broad flats. A majority of these soils are also hydric.
SOMEWHAT POORLY DRAINED - water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. Wetness restricts the growth of mesophytic plants, unless artificial drainage is provided. Some of these soils are hydric and many contain inclusions of hydric soils.

We have discussed soil surveys in general including content and availability, soil classification with respect to wet soils, hydric soils and natural drainage classes. These can be valuable tools in planning and managing forest lands.

TIMBER HARVESTING CONSIDERATIONS FOR SITE PROTECTION IN SOUTHEASTERN FORESTED WETLANDS

W. Michael Aust

ABSTRACT.-- Approximately 11 million hectares of forested wetlands are located in the Southeastern United States and these wetlands provide numerous benefits to society, including the production of timber. Timber harvesting operations are generally considered to be compatible with the long-term sustainability of forested wetland functions and harvesting operations have been developed to avoid and reduce site impacts. Potential site impacts include those affecting site hydrology, water quality, soil properties, and site productivity. Mitigation techniques for harvesting-disturbed sites include mechanical and chemical amendments, but avoidance of the disturbance is preferable. Avoidance of the impact may require additional planning, recognition of site conditions, or equipment and operation modifications.

INTRODUCTION

Forested wetlands have received increasing attention from federal and state agencies, private and public groups and organizations, and the general public since the late 1970's. The scrutiny of these groups is partially motivated by the increasing recognition of the wetland ecosystem functions (processes) that may provide values to society. Examples of wetland functions include the processes associated with wetland hydrology (e.g., floodwater storage), water quality (e.g., denitrification, sediment trapping), nutrient cycling and food chain support (e.g., nutrient uptake, carbon export), habitat (e.g., net primary productivity), and socioeconomics (a generic functional category for all processes contributing to societal values). Societal values created by wetland functions include reduced flood insurance premiums, reduced water treatment costs, commercial fish production, hunting fees, timber production, and recreational benefits (Sather and Smith; 1984; Walbridge, 1993).

Forestry operations within wetlands are currently exempt from the federal Clean Water Act permitting process (Section 404) if the activities meet the following conditions:

1. The activity is not a conversion of a wetland to an upland,
2. The activity is part of an on-going operation,
3. The activity has not lain idle so long that hydrologic operations are necessary,
4. The activity does not contain any toxic pollutants, and
5. The activity uses normal silvicultural activities that comply with the forestry Best Management Practices (BMPs).

It is important to recognize that there are 15 Federal BMPs relating to forestry activities (Cubbage et al., 1990; Siegle and Haines, 1990) and that some state BMPs may have mandatory provisions in wetlands areas (Aust, 1993).

Cubbage and Flather (1993) used the National Resource Inventory of 1982 (USDA Soil Conservation Service, 1987) to compile the forested wetland acreage in the southeastern United States by stand type. Combined, bottomland hardwoods (4.4 million hectares), baldcypress-tupelo (1.7 million hectares), pine-hardwood (1.5 million hectares), bay-tupelo (1.4 million hectares), pine (1 million hectares), other forested wetlands (0.5 million hectares) and non-stocked forested wetland areas (0.2 million hectares) are found on 10.7 million hectares of nonfederal forest land in 14 southeastern states.

HARVESTING IN WETLANDS

Historically, timber harvesting operations within forested wetlands have been difficult. During the late 1700's and early 1800's wetland logging consisted of relatively small float logging operations in wetter areas and oxen, horse, or mule logging on the drier sites. Harvesting of the drier areas sometimes preceded agricultural conversions. Around the turn of the 20th century, large scale harvesting operations became more prevalent in the forested wetlands of the southeast, primarily due to the advent of steam powered cable harvesting systems. Steam engines and winching systems were commonly mounted on rail cars

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or pullboats. The cables were pulled out into the stands by a series of block and tackles, animal-, or human-labor for distances up to 1/2 mile. These early cable operations usually dragged logs along the ground and in some instances actually created channels that connected with the stream.

Between 1920 and the early 1960's, logging in wetland areas used a variety of labor-intensive systems, including tracked and rubber-tired skidders, and modified cable systems. During that last 30 years, the rubber-tired skidder has become the most commonly used machine for most wetland harvesting operations. Several options are widely used with these skidders in order to better facilitate wetland harvesting. Skidder options include cable, grapple, or cable-grapple attachments, dual tires, or ultra-wide, high-flotation tires. Other wetland harvesting systems that are being used or considered for use in forested wetlands wide-tracked skidders and feller-bunchers, forwarders, cable systems, and aerial systems (Jackson and Stokes, 1991; Reisinger and Aust, 1990).

POTENTIAL IMPACTS OF WETLAND HARVESTING

Traffic and Soil Properties

Water controls the degree of traffic disturbance that occurs during wetland logging. If a soil is dry, normal logging traffic has minimal effects on soil properties, excluding situations such as heavily trafficked log decks or primary skid trails (Burger, 1990; Greacen and Sands, 1980). As the soil moisture content increases, a soil approaches the plastic limit and traffic may mold the soil (Baver et al., 1972). The plastic limit is partially controlled by soil texture, soil structure, and soil organic matter, but soil moisture is the primary controlling factor. Soils at or near the plastic limit are more easily compacted and this compaction can reduce soil pore spaces. As the soil moisture content approaches saturation (liquid limit), the trafficked soil matrix will exhibit fluid-like properties (Greacen and Sands, 1980). Traffic on a saturated soil may churn the soil matrix and destroy soil aggregates. Soils that have received this churning are referred to as puddled soils (Burger et al., 1988).

Compaction and puddling can have several negative effects upon soil physical properties. Either disturbance can increase soil bulk density and decrease soil macropore spaces (the larger soil pores that allow air to enter and water to drain from the soil). Reduction of macropore space will reduce the rate of water movement within the soil profile (hydraulic conductivity) (Baver et al., 1972). Because the water flows more slowly within the soil profile, the soil chemistry may undergo several changes. Soil oxygen levels and soil reduction-oxidation potentials would decrease. Simultaneously, the soil pH values would move toward neutrality. The reduced conditions and more neutral pH commonly alter additional soil chemical properties, including nitrogen, phosphorus, iron, and availability and levels of toxins in the soil solution (Ponnamperuma, 1972).

Compaction and puddling may also alter soil physical properties such as soil strength and soil structure. The increased bulk density would result in higher soil strength during dry conditions, but decreased soil strength as a result of trafficking is common on wet sites. The increased bulk density would often increase soil volumetric water content and soil strength would remain low as long as the soil remained moist (Burger et al., 1991). Puddling also may destroy soil structure and allow clay particles to become reoriented in such a way that the settled clay layers further impede the movement of soil air and water (Aust et al., 1994).

Rutting and Site Hydrology

Removal of the trees via harvesting will reduce the transpiration of water from the site and this is usually expected to result in an increase in the water table. Perison et al. (1993) evaluated the effects of timber harvesting in a blackwater swamp and found that water tables were nearer the surface following harvesting. However, Lockaby et al. (1994) found that the water table was actually lowered by timber harvesting. They hypothesized that the lowered water table was the result of increased soil temperatures on the dark organic soils of this study site and the increased temperature caused greater evaporation of water.

Aust et al. (1993a) evaluated the effects of salvage timber harvesting and deep skidder rutting on the hydrology of a wet pine flat. The water table was closer to the soil surface immediately after the salvage operation, although no live (transpiring) trees were harvested and no rainfall occurred during the measurement period. Apparently, the puddling associated with the primary skid trails had altered the lateral flow of subsurface water and restricted soil drainage.

It is commonly believed that poorly-drained wet sites are more sensitive to hydrology alterations associated with harvesting. However, Aust et al. (1994) evaluated the effects of compacted and rutted skid trails on site hydrology and concluded that the hydrology of poorly- and very-poorly-drained soils was less alterred by skidding than are moderately-well-drained or somewhat-poorly-drained soils. Poorly-drained soils have extremely slow rates of hydraulic conductivity before and after trafficking.

Rutting and Water Quality

Shepard (1993) reviewed several current studies of the effects of forest management on water quality in forested wetlands of the southeastern coastal plain. Overall, the studies indicated that harvesting effects on water quality effects were either minimal or nonexistent. The reviewed studies did assume that forestry BMPs would be used.

Lockaby et al. (1994) compared the effects of aerial and ground-based log removals in small blackwater stream bottoms having organic soils. They concluded that the harvests had insignificant effects on total suspended sediment or water nitrogen or phosphorus levels.

Aust et al. (1991a) compared sediment removals in a cypress-tupelo red river bottom that had been harvested with helicopters and rubber-tired skidders. Both harvest treatments trapped more sediment than did an undisturbed control. A remeasurement of this area at age 7 years revealed that the helicopter and skidder logged areas had trapped over 9 cm of sediment in seven years whereas the undisturbed area had trapped 4 cm of sediment in the same time period (Zaebst and Aust, 1993). Similar results were found in a blackwater river bottom following similar harvest treatments (Perison et al., 1993).

Rutting and Site Productivity

Murphy (1983) examined the growth of radiata pine grown in skid trails compared to trees grown in adjacent, undisturbed areas. He concluded that the form, health, and vigor of the skid-trail-grown trees was significantly reduced.

Zaebst and Aust (1993) compared skidder and helicopter logging at age 7 in a tupelo-cypress pond in southwestern Alabama. The tree densities and average diameters were not affected by treatments, but the average tree heights were 7.5% shorter in the skidder-logged areas. However, the skidder-logged area had better stocking of the desired species (water tupelo). The reduced tree heights were attributed to the poorer aeration within the skidded area (Aust and Lea, 1992). It is hypothesized that the higher proportion of water tupelo in the skidded area was due to the flood tolerance of water tupelo as compared to the black willow, Carolina ash, and pumpkin ash in the helicopter-logged areas.

Powell (1992) compared the growth of thinned loblolly pine along rutted skid trails to the growth of thinned loblolly pine further away from the trail. Although the effects of the rutting were confounded by differences in thinning intensities, he concluded that the trees adjacent to the trail were growing faster. Trees that had been damaged during thinning grew well, but trees that grew near ruts and were damaged grew very poorly. Apparently, either situation stressed the tree and made it more susceptible to additional impacts.

Scheerer (1993) compared the growth of two-year-old loblolly pine seedlings that were grown on skid trails that had been either rutted or puddled with trees on adjacent areas that had not been trafficked. Both disturbances reduced tree survival, total height, and seedling vigor.

Natural Recovery and Artificial Mitigation

A site's ability to naturally recover from a disturbance will depend on the degree of the disturbance and the degree to which natural ameliorative agents are active. Undoubtedly, some areas will recover naturally, but the estimated time of natural recovery ranges from 5 to 60 years (Burger and Aust, 1990). Studies in cooler climates indicate that the freezing and thawing of soils leads to an eventual recovery of soil structure (Blackwell et al., 1985), but freezing and thawing is minimized in the southeast. Soils having a high proportion of shrink-swell clays may recover faster (Culley et al., 1982). The Black Prairie Region of Mississippi and Alabama has both vertisols and mollisols with relatively high concentrations of montmorillonite clay. Soils in this area shrink when dry and swell when wet, speeding the natural recovery process.

Soil organisms are a third important type of natural ameliorative agent. In wetland sites, the burrows created by crayfish may extend hundreds of feet laterally within the soils and serve as an important drainage mechanism (Aust and Lea, 1992).

Scheerer (1993) compared the effects of mechanized skid trail amelioration on the growth of 2-year-old loblolly pine seedlings in rutted and puddled skid trails. Main treatments included a control, disking, bedding, disking and bedding, with a split plot treatment of fertilization. All treatments were partially effective in ameliorating the effects of rutting, disking was not effective in ameliorating the effects of puddling. McKee and Hatchell (1987) evaluated the effects of similar mitigation treatments on similar sites and stands at age 12-years, and concluded that a mechanical treatment combined with fertilization resulted in the best ameliorative treatment.

Economic Consequences of Rutting

Rutting and puddling are highly visible in wetland areas and this visibility accentuates the potential problems. Rutting and puddling in wetland areas can cause problems, but not necessarily for the commonly cited reasons. The federal Clean Water Act has provided the impetus for much of the concern over timber harvesting in wetland areas, but research has indicated that water pollution due to timber harvesting is minimal or nonexistent in forested wetlands (Shepard, 1993).

The second commonly cited consequence of rutting in wetland areas is that it will lead to decreased long-term site productivity. Several short-term studies have indicated that this is indeed true (Murphy, 1983; Scheerer, 1993; Zaebst and Aust, 1994), but early results from forestry research have often not been apparent at rotation age.

Sites that are subject to severe rutting often have increased harvesting costs because of the addition machinery costs, both in time and equipment wear. Many of the current machines are rugged, but still require more maintenance and repair than similar machines operating on upland sites. This cost is often overlooked.

Lastly, a hidden cost of rutting is the reduction of the operational window. A wet site that is severely rutted will require more time and equipment hours to site prepare. In some cases the site preparation operation may be delayed for two or three years, effectively increasing the rotation age, even if site productivity has not been reduced. This time cost may actually be greater than any site productivity costs.

RECOMMENDATIONS

Burger and Aust (1990) reemphasized some standard suggested mechanisms for avoidance of the rutting problem: (i) recognition of site conditions, (ii) better use of existing technology, (iii) better planning, and (iv) development of new technology.

Recognition of Site Conditions

Increasingly, information about company lands is being entered into GIS systems that allow rapid assessments of overall site characteristics prior to harvesting operations. Some organizations have the water management structures in place that allow sites to be dried before harvesting so that impacts can be avoided. Also, the Soil Conservation Service soil surveys are being used more often to recognize inherent site conditions and potential problem areas.

Better Use of Existing Equipment

Perhaps the most common technique used to minimize the impact of wet site harvesting is to equip a skidder with dual tires or ultra-wide, high-flotation tires. Wide-tires and dual-tires do increase machinery production on wet sites, but may not decrease traffic impacts. Burger et al. (1988) evaluated the performance and impact of three tire sizes and three gear speeds on the machinery production and site impacts in a wet pine flat in Georgia. Wider tires did not reduce soil impacts, but did increase machinery production. Aust et al. (1991b, 1991c, 1993b) evaluated the effectiveness of wide-tires in reducing trafficking impacts on mineral soils in Alabama and South Carolina and an organic soil in Alabama. Overall, there was no conclusive evidence that tire width alone could be used to predict the level of site rutting, but site rutting did follow a distinct pattern: single-tired skidder ruts > dual-tired skidder ruts > high-floatation, ultra-wide-tire skidder ruts. During the course of these controlled studies, three operational harvesting jobs were also evaluated. From an operational viewpoint, the wide tires were used to extend the range of sites that could be trafficked thus reducing their effectiveness in reducing the impacts.

Better Planning

There is continued interest and controversy surrounding the use of designated skid trails in wetlands. One group believes it is better to concentrate the disturbance within a smaller area where rutting is inevitable (designated skid trails). The alternative viewpoint is that overall site impacts would be minimized by having a lower level of impact over a larger area (dispersed skid trails). Both arguments may be valid on different sites (Burger, 1990; Morris, 1990). If the site has very low soil strength and the machinery is going to puddle

the soil and impede the flow of water after a single pass, then designated skid trails would minimize the area of disturbance. If the site has a higher machine-bearing capacity, and the soil would be puddled only after repeated passes, then dispersal of the traffic would minimize the impact. As with most wetland issues, the best option (dispersal or designated) will be dependent upon the season and site characteristics.

Development of New Technology

Over the last 15 years several new systems have been suggested for minimizing site impacts of wetland harvesting. These include helicopter harvesting systems and tracked forwarders, fellers, and skidders. At present, the aerial systems are limited in use because of the large expense associated with their operation. Tracked equipment is becoming more widely accepted, but the cost of the machinery is still of major concern to operators.

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APPLICATION OF HYDROGEOMORPHIC PRINCIPLES AND FUNCTION TO ASSESSMENT OF DRAINAGE INTENSITY IN FORESTED WETLANDS

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Abstract.--Minor drainage of wetlands does not have a broadly accepted technical definition. To facilitate detection of thresholds and interpretation of the effects of drainage on wetlands, we provide a framework to evaluate changes to their functions. Changes in functions due to drainage may be assessed relative to reference standards for particular hydrogeomorphic (HGM) classes. Hydrologic alterations that result in major changes of state, such as change in HGM class, would be not be considered minor and thus would not qualify for the 404(f) silvicultural exemption. More subtle changes may be difficult to detect by measuring hydrology alone, but the significance of alteration can be judged ultimately by corresponding reductions or alterations in functions. A given intensity of drainage may be considered minor or major depending on what HGM class is affected and the degree to which functions change. Use of silvicultural reference standards are needed in order to determine levels of functional performance and to test the capability of sites managed for silviculture to return to a reference condition. The capacity to return to reference condition at any point in the silvicultural rotation is a test that drainage is minor.

INTRODUCTION

Minor drainage is not a technical term and does not have a long history of common usage. Consequently, we cannot apply this term to the various activities in wetlands without first examining drainage that goes beyond what most reasonable people would consider "minor." To provide a framework for examining the continuum from major to minor drainage, we use a hydrogeomorphic classification (HGM) of wetlands (Brinson 1993) as a starting point. After providing some examples of HGM classes that commonly receive drainage, we will examine how sources of water differ among these classes. This approach is intended to illustrate how the same drainage activity may have different effects depending on the HGM class being drained. Several examples are used to illustrate how various combinations of drainage activity and geomorphic settings interact to affect commonly recognized wetland functions. The extent to which wetland functions are affected by drainage can be assessed, and becomes the metric for evaluating levels of drainage activity.

A relationship between forest productivity and site drainage has been identified in several studies (Klawitter and Young 1965; Maki 1971; Terry and Hughes 1975), and attempts continue to quantify this relationship (Campbell 1976; Liepa 1990; Valk et al. 1990). "Wet" sites were traditionally drained to allow access to timber during harvest. On-site observations led some to suspect that drainage also improved growth. In Finland, where much of the forested area is swampland, systematic forest drainage began in 1908 resulting in accelerated tree growth. Finland's Forest Improvement Act of 1928 officially recognized forest drainage as one of several legislated and state-subsidized forest improvement activities (Metsaojitussaatio 1970).

In the Southeast (USA), thousands of hectares of forests on wet flats have undergone some form of water control. Since 1960, mostly through drainage by ditches, the extent of drainage in the Coastal Plain was controlled by four objectives: (1) to improve access for harvest, fire protection, and other management activities; (2) to facilitate regeneration of pine seedlings; (3) to increase growth or reduce rotation age (Hewlett 1972), and (4) to reduce soil compaction and puddling (Pritchett and Fisher 1987).

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GEOMORPHIC SETTING

The geomorphic settings or landscape positions of wetlands are depression, slope, flats, riverine, and fringe. Because effective drainage depends in part on the water sources of each of these settings, it is critical to understand differences among HGM classes.

Depression and Slope Wetlands

Depression wetlands are geomorphic features with lower elevations than the surrounding landscape. Carolina bays, some oxbows, and the playas and potholes from the prairie states to the arid southwest are good examples. They may lack channelized flows or may have various combinations of channelized inlets and outlets. Because they vary greatly, no generalizations can be made about groundwater recharge and discharge between wetlands and deeper aquifers.

Many depression wetlands of coastal plains of the Southeast are merely surface expressions of water tables. As such, the dominant water sources in these wetlands are often precipitation and shallow subsurface flow from the upland. The capacity of depression wetlands for surface water storage depends in part on whether there are surface inlets and outlets, the elevation of the outlet relative to depression contours, and the shape and size of the depression.

Slope wetlands receive groundwater discharge from either subsurface saturated or unsaturated flow in addition to precipitation and varying amounts of overland flow. Relative to depression wetlands, slope wetlands have lower capacity for surface water storage because there is little opportunity for deep ponding. Often, the size of individual slope wetlands is much smaller than other wetland classes. They occur sporadically on hillslopes and at breaks in slope (Winter 1988) and quite frequently in the Southeast at the interface between floodplains and uplands.

Flats that Occur on Topographic Highs

Common and extensive wetlands in the Southeast are the large, flat interfluves or terraces that receive precipitation as the only source of water. Generally they lose water only by evapotranspiration (ET) except when surface water storage is filled. Consequently, their water tables fluctuate greatly during warm periods when ET creates drawdown conditions and precipitation causes water table rebound.

Flats can be divided into two broad categories: those with predominately mineral soils such as wet pine flats and those with histosols or histic epipedons such as many pocosins. In the original HGM classification, organic soils were considered extensive peatlands because of the unique edaphic conditions attributable to peat (Brinson 1993). Peat has a high capacity for soil water storage because of the large quantity of pore space above field capacity. Some mineral soil flats have highly permeable surficial horizons, but percolation may be reduced by the presence of a spodic horizon or other semi- or impermeable soil horizon.

Fringe Wetlands

Fringe wetlands are adjacent to large bodies of water that reduce the potential for significant water table drawdown. The most obvious examples are wetlands adjacent to estuaries and large lakes. They include

marshes (tidal saltwater marshes and freshwater marshes) and forests (freshwater swamps and mangrove swamps). Because of frequent tidal flooding, most salt marshes and mangroves do not undergo prolonged periods of water table drawdown. Sea level controlled wetlands also occur on the landward side of fringe wetlands and beyond the influence of regular tidal inundation (Brinson 1991). They may receive supplementary water from freshwater sources including groundwater discharge and overland flow. Even when these sources are lacking, the hydrostatic head created by sea level minimizes the extent to which they can experience water table drawdown because of their virtually infinite source of water from below. A final variation is the sea-level controlled, but nontidal marshes and swamps of the Albemarle-Pamlico peninsula of North Carolina (Moorhead and Brinson in press). They are nontidal because the large size of the estuary is relatively insensitive to the relatively small volumes of tidal exchange that occur on any given tidal cycle.

Riverine Wetlands

Riverine wetlands occur as long and linear features of the landscape (Brinson 1990). Runoff from uplands and discharge of groundwater converge to flow over long distances along riverine corridors. The effects of unidirectional flow of water create a strong geomorphic signature on the landscape making riverine wetlands one of the easiest to identify.

Overbank flooding is a common and essential water source for most riverine wetlands with well developed floodplains. Two broad classes are commonly recognized in the Southeast: (1) riverine forests of alluvial streams that originate in the Piedmont or the mountain physiographic provinces and (2) riverine forests of blackwater streams originating in the coastal plain. These are often referred to respectively as red river and blackwater bottomlands. Usually several plant communities are recognized including the nearly permanently saturated cypress-tupelo-overcup oak swamps, the frequently flooded ash-sweetgum-hackberry swamps, and the less frequently flooded oak-hickory swamps. Important components of many riverine wetlands are red maple and sweet gum. Variations of these groups are described in Wharton et al. (1982). Locally, they may be called first and second bottoms if only two are recognized. These communities may be spatially interspersed in large floodplains such that cypress-tupelo swamps can be found at great distances from the river, and in proximity to second bottoms of higher elevations. In small streams, elevational zones are so compressed that it is more difficult to separate distinct plant communities.

WETLAND FUNCTIONS

What are Functions?

Wetland functions are the normal activities or actions that wetland ecosystems perform, or simply, the things that wetlands do. Because of the vagueness of this definition, examples will be given to clarify what is meant by wetland functioning. These are listed in Table 1 along with on-site and off-site effects of the functions discussed below.

One of the problems with using the term function is the baggage that accompanies its use in tandem with the term "value". Functions are the things wetlands do whether or not humans happen to use them. Examples are water storage, biogeochemical transformations, plant community maintenance, and animal community maintenance. Many functions are the basis for the flow of goods and services that society uses such as flood control, water quality maintenance, and harvestable products such as timber and game. Society tends to recognize that these goods and services have "values." Many of the valued goods and services become part of

the market system. As such, they are subject to changes in the market even though the ecosystem may not have undergone any change. One of the best examples is the low value attributed to swamps and marshes as little as 50 years ago. They were often held in such low esteem in their wet condition that economic incentives were provided by the Federal government to drain them and to convert them to entirely different uses. One reason that the use and alteration of wetlands is so controversial today is that policies toward them have been reversed, in large part due to the Clean Water Act and associated regulations. Consequently, by considering only functions and not collateral values, goods, and services, we rely on the relative quantity of various ecosystem functions rather than values that may change from one year to the next.

Examples of Variations of Functions among HGM Classes

The brief description of some common HGM classes provided above serves as background for comparing how functions differ among wetlands. The surface water storage function differs between slope and depression wetlands as one example. Biomass production varies greatly among wetland classes, generally being higher in the fertile riverine wetlands than the nutrient poor pocosin peatlands. Another example is food web support for the maintenance of animal communities. Few would question that tidal marshes, with their complex assemblage of estuarine fish, filter-feeding mollusks, and wading birds have higher secondary production than wet pine flatwoods. By citing specific examples from the generic list of functions in Table 1, other examples can be developed to illustrate differences in wetland functions.

Off-site Effects of Functions

Table 1 also lists the on-site and off-site effects of functions. On-site effects are the ones that occur within the wetland that is performing the function. Some of the most commonly recognized functions, such as surface water storage, have off-site effects such as reducing downstream flood peaks. Similarly, some of the biogeochemical functions are best recognized for their off-site effects such as the reduction of nutrient loading downstream from the wetland. Consequently, the effect of changes in functions within wetlands can be manifested elsewhere. One example with broad geographic implications is the maintenance of habitat for neotropical and waterfowl migrants.

Based on the various combinations of functions, on-site effects, and off-site effects of different magnitudes, it is apparent that changes in functioning can take on many quantitative and qualitative dimensions. What is needed is a framework for assessing these potential changes in a systematic fashion. The HGM functional assessment method under development by the U.S. Corps of Engineer Waterway Experiment Station is an example of an approach that can be adapted to fill this role.

CHANGES IN FUNCTION AS A CONSEQUENCE OF DRAINAGE

The following discussion presents several examples of changes in wetland function that may occur as a result of drainage. They are summarized in Table 2.

Drainage that Alters Soils

If the HGM class is extensive peatland, one of the most notable functions is vertical accretion and maintenance of organic matter. Vertical accretion has on-site effects of increasing site elevation and making the site less vulnerable to deep flooding. Off-site effects include sequestering of carbon dioxide from the

atmosphere and increasing organic carbon export to downstream ecosystems.

Drainage may reverse the functioning of extensive peatlands by increasing the rate of oxidation of organic matter due to greater aeration by lowering the water table. This would reverse both on-site and off-site effects by respectively causing subsidence and initiating a net efflux of carbon dioxide. These are significant not only because of changes in rates, but because the process of accumulation can be reversed. With a lower water table, fire frequency may also increase, thus leading to an even more rapid subsidence from peat burns. As summarized in Brinson (1991), published rates of peat subsidence are about one order of magnitude more rapid than vertical accretion.

Drainage that Alters Vegetation

Using mineral soil flats as the example of HGM class, one of the functions is plant community maintenance. This function has on-site effects of maintaining species composition and physiognomy of the vegetation. An off-site effect is the support of neotropical migrant birds. A significant alteration of drainage may change both of these through the intermediate effect of a gradual and eventual conversion to plant species with more upland affinities and intolerance to flooding. If longevity of individuals is a predictor of species replacement, then ground cover (herbaceous stratum) would be expected to change more rapidly than the shrub layer, and the shrub layer would be expected to change more rapidly than the canopy species. Indirect consequences of drainage could be important also such as increasing fire frequency. If alterations pass the point that the wetland cannot be returned to its previous condition, drainage is not minor. Nutrient enrichment in combination with drainage may lead to dominance of species other than native vegetation. While the intent of silvicultural exemptions is to allow dominance by pine in most cases, the test is whether the sites could be successfully returned at any time in the rotation to a mineral soil flats wetland with sustained native vegetation.

Drainage that Changes HGM Class

Riverine wetlands have many functions of which three will be discussed here. These include food web support for fish, particulate (sediment) removal, and nutrient transformations in floodwaters. On-site and off-site effects are given in Table 2. If the riverine wetland is diked so that it no longer receives overbank flow from the river, the effects on-site would be immediately discernable because the sources of water have changed. The riverine wetland would have been converted to a site with depression characteristics in spite of the fact that riverine geomorphic features, such as oxbows and meander scrolls, would persist. In the absence of overbank flooding, depths of inundation are unlikely to reach pre-alteration levels, fish from the river channel would be excluded from moving to and feeding on the floodplain, and deposition of sediments would be virtually absent because overbank flooding had been eliminated. Consequently, a change in HGM wetland class has occurred which would alter functions dramatically and predictably.

The Same Drainage Intensity has Dissimilar Effects

In this example, two HGM classes receive the same drainage "intensity" (e.g., length and size of ditch per unit area of land). Both the depression wetland (a cypress dome) and a flat (wet pine flat on a hydric phase of Rains soil, for example) have hydrophytic vegetation, anaerobic biogeochemical cycling, and redoximorphic soil properties as on-site effects of the function of surface water storage. An off-site effect is decreases in downstream flood peaks. In this case, the cypress dome is radically altered from its original condition by being converted to a drier site with diminished wetland area and an acute change in species composition

resulting from drainage-related fires. The wet pine flat merely undergoes a relatively uniform transition from wet to mesic pine flat. The point is that the same apparent intensity of ditching deflected one wetland farther from its original condition than the other. Therefore, activities in wetlands should be interpreted by the amount of effect that they have rather than assuming similar impacts.

BASIC PRINCIPLES FOR MINOR DRAINAGE ISSUES AND HGM FUNCTIONAL ASSESSMENT

When designing a wetland drainage system or upgrading an existing system, one needs to be able to establish it as a minor drainage system to qualify for the 404(f) silvicultural exemption. In order to do this, criteria need to be established to define minor drainage and differentiate it from major drainage. If, as indicated in one of the examples above, major drainage intensity in one landscape may be minor in another, then the drainage must be tailored to landscape position or some other characteristic of the wetland.

One of the four stated forest drainage objectives implies that an immediate goal is reasonably rapid removal of surface water. Thus, the principal water source as defined by the HGM classification determines configuration of the drainage system. The principal water source for riverine systems may be groundwater and overbank flow; for depression systems groundwater and surface water, and for flats direct precipitation. These variations in topographic position, water source, and flow vectors mean that no single drainage configuration can be specified that could be uniformly implemented across a group of HGM classes, let alone a single HGM class, and be considered to be minor. Minor drainage also cannot be defined accurately for large regions where there is much physiographic or climatic variation. The focus should be on which landscapes are most vulnerable to drainage. Thus, the degree of drainage (minor or major) must be defined not only in the context of physical attributes of the drainage system, i.e., depth of ditch, distance between ditches, etc., but also in terms of changes in function.

Long-term practices that alter dominance and species composition of vegetation (including the introduction of exotics), hydrologic flow paths and water storage, pedogenic processes, and topographic status (both internal microtopography and relative to adjacent landforms and sea level) represent a change in state and, therefore, would not be considered "minor". This is a major departure from current policy approaches that say "no change in ongoing practices."

In wetlands, water is often the principal driving force for the non-hydrology functions. Changes in the non-hydrology functions can often serve as indicators of the magnitude of alterations to hydrology. We submit that a promising approach to a consistent assessment of "minor" alterations to hydrology through drainage is through the use of HGM classification and functional assessment.

The following discussion outlines an approach to evaluating the nature of change in state through a functional assessment with the emphasis on alterations to wetland hydrology.

WETLAND HYDROLOGY AND FUNCTION

Wetland hydrology is complex and difficult to assess without site-specific studies. We frequently do not have the opportunity or time to collect information for each wetland that would adequately characterize its hydrology. Classification systems such as HGM helps to identify the expected hydrology of a wetland and lead to an appropriate comparisons for assessment. Water source and landscape position are critical to determining wetland hydrology and these are principal determinants of the HGM classification scheme.

Hydrology in turn drives most of the wetland functions we've discussed above and thus can result in major impacts when hydrology is changed.

Alterations of wetland hydrology can also be minor, and thus may occur without significantly impacting many functions. To determine the degree of change in function, an assessment must be completed using reference sets of wetlands for comparison. Because hydrology is so variable over time, yet it controls in part many non-hydrologic functions, it is often easier to detect changes non-hydrologic functions. One example is a change in understory vegetation toward more xeric-adapted species as a result of drainage. The expected change across many functions can often be used to assess the degree of change to wetland hydrology. Alterations to wetland hydrology can be brought about by such activities as artificial drainage, harvesting, site preparation, planting activities, roads, poorly implemented Best Management Practices, and fire lane plowing.

To assess changes in function, the reference system must be of the same HGM class with the same principal water sources, hydrodynamics, and geomorphic setting as the project wetland under consideration.

Minor Drainage Defined

For the purposes of this paper, we define minor drainage as artificial drainage by the construction of ditches and dikes, or otherwise grading of a site to remove primarily surface water without significant changes in wetland function. In silviculture, drainage goals are: (1) to remove primarily surface water for improved access over longer periods of the year, (2) to minimize damage to soil during management activities, (3) to improve regeneration, and (4) to increase tree growth. In some wetlands, it is virtually impossible to implement minor drainage without significant changes in function.

These precepts, definitions, and the preceding discussion are the basis of a rationale for assessing alterations to wetland hydrology in the context of the degree of drainage.

Alterations to Hydrology

We suggest that tests for significant changes in wetland hydrology are best detected as aggregate changes across one or more wetland functions. As a condition of this test of change, (1) the activity is normal silviculture, (2) the activity is on-going and continuous, (3) best management practices are implemented, and (4) conversion of site (wetland to non-wetland) does not occur. Furthermore, if drainage discernably changes flow, circulation, and extent of reach of waters of the USA, then the drainage is significant, and therefore not minor.

There are few cases in the Southeast where forest drainage to remove surface water and/or groundwater does not change the flow and circulation of waters of the USA. For example, the principal water source for a pine flatwood is precipitation and the flow and circulation of water is primarily up and down, i.e., water is lost to ET or groundwater drainage, the latter usually minor. Implementation of drainage to remove surface water in a lateral direction across the land surface to a ditch represents a change in flow and circulation. However, rapid removal of surface water by drainage with little change in the extent of soil saturation (i.e., the water table is not lowered), may only have slight effects on some functions such as abundance and/or occurrence of a particular understory species. Similar circumstances for other HGM types can be cited.

Therefore, we will consider drainage in terms of minor impacts to function as manifested in wetland functions

such as those used as examples in Table 1. (The actual functions will vary with wetland class. Examples are given for illustration only.) When hydrologic alterations are expected to result in gross and immediately apparent changes, the activity triggers a regulatory assessment process that is beyond the scope of this paper. When alterations are expected to result in subtle and/or gradual changes to hydrology, the impacts to functions must be assessed to determine if the activity constitutes minor drainage. In other words, drainage which results in significant changes in function is not minor.

Following this line of reasoning, minor drainage cannot result in (1) a change in HGM class, (2) changes in principal water source or transport vector, and (3) site conversion from wetland to non-wetland.

The Reference System

A reference wetland system is a fundamental component of the HGM functional assessment methodology. The reference system is a set of selected wetlands in the same HGM class that has the same geomorphic setting and principal water source and transport. Each reference set is made up of a continuum of conditions found within the class. Under routine functional assessments, the project site would be compared with target references (reasonably intact wetland ecosystems of the same HGM class which encompasses natural variation of the class), and functions of the project site would be compared both before and after the project with the target.

With the silvicultural exemption, another layer of reference is required, the silvicultural reference. Silvicultural reference sites are those receiving minor drainage that is sufficiently benign that changes in vegetation structure do not result significant or long term changes or departures in "function." What makes this a silvicultural reference is the demonstration that these sites can be returned to the functional condition of the target reference. This comparison is shown in Figure 1 (target vs silvicultural). Such an undertaking will require joint efforts by timber companies and regulatory agencies to reach consensus on the maintenance of functions. The test for maintenance of functions is whether the silvicultural references can be returned to the target reference condition at any point during the rotation. While tree age would provide an scale for arraying sites, indices of function would be determined from a number of factors that relate specifically to the individual functions being assessed.

Use of reference in this manner allows for assessment of a project's impacts before implementation. Cyclic or temporary hydrologic alterations resulting from normal silvicultural activities, and not violating the aforementioned precepts, are incorporated into the assessment methodology through the use of a range of silvicultural conditions in the reference set and specification of capacity to return to target reference condition.

Project Area and Impact Area

It is critical that both project area and impact area for a minor drainage determination be identified. Drainage impacts cannot be averaged to determine if functions are affected over a large project area in several stages of silvicultural rotation. On the other hand, determining impacts only along the ditch perimeter would be biased because impacts to function along this narrow band are likely to be major if drainage is to be effective.

We define the project area as that tract for which a silvicultural prescription has been prepared and the tract will be managed (harvested, etc.) as a single unit. The impact area is that area within the project area in which changes to function may occur due to the drainage activity. The impact area for drainage ditches

placed to remove surface water is the entire area, including the ditch, from which surface water is removed. For ditches placed to remove groundwater, the impact area is that area on either side of the ditch, including the ditch, in which the water table has been lowered.

FUTURE DEVELOPMENTS

We have outlined in this paper a rationale for using functional assessment based on a HGM classification system to determine if a silvicultural drainage activity may classified as minor. The functional assessment procedures have been field tested for a series of HGM classes across the USA and a series of case studies are in preparation to demonstrate the method. All work is being conducted under the auspices of the U.S. Army Corps of Engineers Waterways Experiment Station. A final report with rationale for development, field methodologies, and case studies will be available in early 1995.

SUMMARY AND CONCLUSIONS

A general strategy has been described for assessing minor drainage in silvicultural operations using the hydrogeomorphic functional assessment approach. The concept is based on comparing functions of target reference wetlands with sites altered by drainage. Drainage is considered minor if a site can be restored at any point in the silvicultural rotation back to the original functioning condition of the target reference. Although the functional assessment methodology is still under development, it has been shown to be sensitive to changes in function resulting from site alteration (Gaskin et al. 1994). The following summarizes the main points and conclusions of the paper.

The nature of minor drainage.

- Minor drainage cannot change hydrogeomorphic (HGM) class, alter principal source or transport vectors of water, or cause site conversion from jurisdictional wetland to non-jurisdictional wetland.
- To be considered minor, the site being drained must be capable of sustaining the functions (with the exception of maintenance of native vegetation for silviculture) of the target reference system.
- If drainage impacts are gross and immediately evident in terms of significant loss of function, the drainage is not minor and falls under the recapture provisions of 404.
- The entire drainage impact area must have no significant loss of function for the activity to be considered a minor drainage.

Detection of major drainage.

- The HGM method is a powerful tool for classifying wetlands and assessing functions.
- Wetland functions are an expression of what a wetland does and the functions are measurable.
- Using HGM as a framework, a functional assessment methodology tied to reference conditions can be used to assess effects of subtle or gradual alterations to wetlands.
- If drainage is minor, hydrologic impacts are subtle, gradual, and slow to be manifested -- changes to functions in comparison to reference is best and most consistent method of assessment.
- HGM and functional assessment can be used to determine the consequences of hydrologic alteration (e.g., when the impact of impairment of flow and circulation and reduction of extent of reach is not readily or immediately apparent).
- The minor drainage functional assessment test should be applied before drainage activity occurs.

- Target reference wetlands should be used as templates for restoring functions to previously degraded or altered sites.
- Before this suggested methodology can be applied to assessing minor drainage, field testing and case studies must be conducted to meet the specific purpose of using the HGM methodology to assess effects of minor drainage in forested wetlands.

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Table 1. Relationship of functions, effects of functions, corresponding societal values (based on goods and services), and indicators of function for riverine wetlands. The list of functions is not comprehensive.

EXAMPLE OF FUNCTION	EFFECTS OF FUNCTION	CORRESPONDING SOCIETAL VALUE(S)	INDICATORS OF FUNCTION
HYDROLOGIC			
Dynamic surface water storage	Reduced downstream peak discharge	Reduced damage from floodwaters	Presence of floodplain along river corridor
Long-term surface water storage	Maintenance of base flows & seasonal flow distribution	Maintains fish habitat during long dry periods	Topographic relief on floodplain
Subsurface storage of water	Maintains hydrophytic biotic community	Contributes to biodiversity	Presence of hydrophytes
BIOGEOCHEMICAL			
Transformation and cycling of elements	Maintains nutrient stocks within wetland	High rate of wood production	Presence of viable forest community
Retention and removal of dissolved elements	Reduced loading of nutrients downstream	Improved water quality	Data indicating nutrient outflows lower than inflows
HABITAT AND FOOD WEB SUPPORT			
Maintain characteristic plant community	Habitat structure for nesting, cover, etc.	Support of furbearers and waterfowl	Mature forest community
Maintain characteristic energy flow	Supports populations of vertebrates	Maintains biodiversity	Species diversity of vertebrates

Table 2. Changes in wetland functioning as a result of drainage. The examples are not comprehensive.

HGM Class	Effect of Drainage	Function(s) Affected	On-Site Effects	Off-Site Effects	Specific Alteration	Changes in Functioning
Extensive Peatland	Alters soils	Vertical accretion of peat	Increases site elevation & drainage patterns	Sequesters carbon dioxide from atmosphere	Ditching & drainage lowers water table	Reduces or reverses vertical accretion
Mineral Soil Flat	Alters vegetation	Maintenance of plant community	Sustains species composition	Sustains neotropical migrants	Ditching and drainage lowers water table	Species in understory & bird guilds
Riverine Bottomland	Change in HGM class	Fish food web; nutrient transformation	Complexity in food web; supply of nutrients	Enhances fish population growth; maintains water chemistry	Installation of dikes; conversion to depression-like condition	Decreases fisheries yields; decreases water quality
1. Depression (cypress dome) 2. Wet pine flat	Same drainage intensity with dissimilar effects	Surface water storage	Maintains hydric soils; anaerobic cycles; hydrophytic vegetation	Decreases downstream flood peaks	1. Median ditch 2. Ditched at 100 m intervals	1. Loses hydrophytes; burns 2. Changes from mesic/hydric to dry pine association.

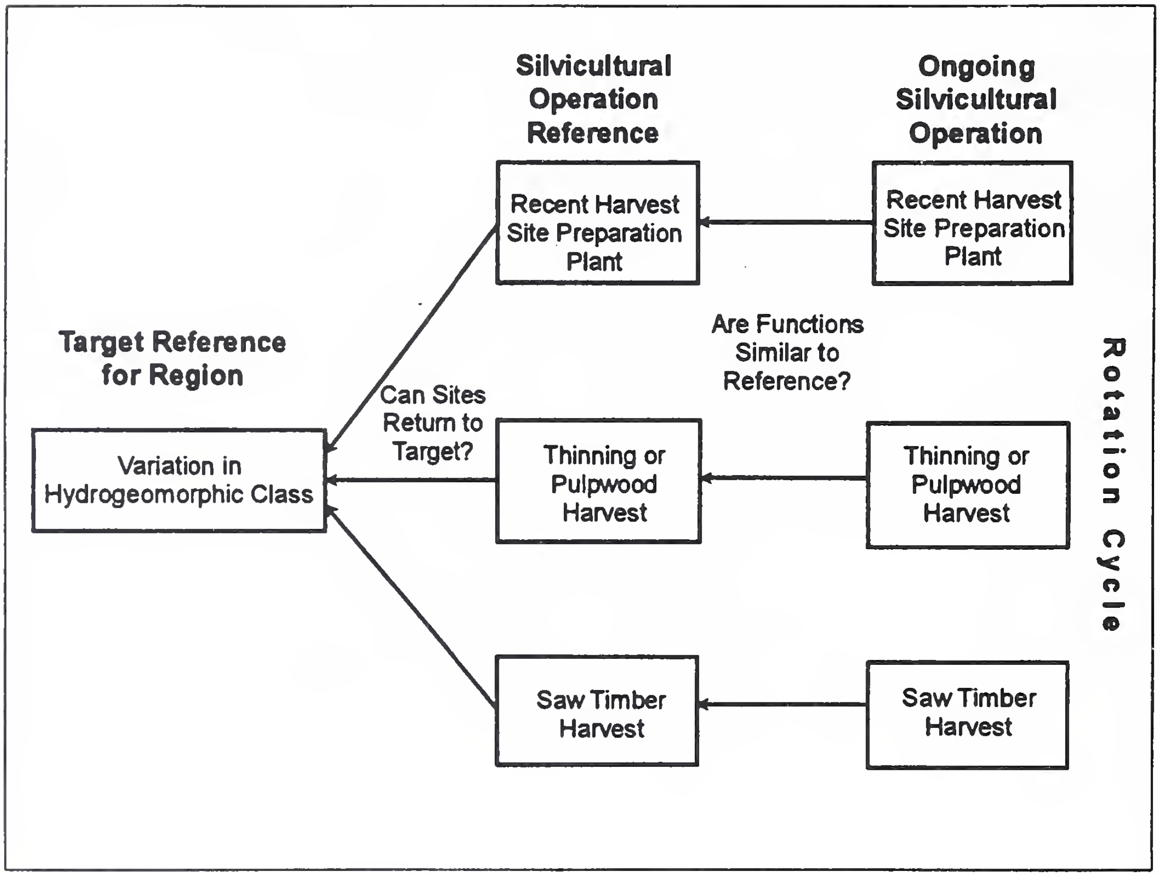

Figure 1. The relationship between the target reference system, silvicultural references, and silvicultural project sites. A test of minor drainage is demonstration that the silvicultural references can be returned to target reference. The test of minor drainage for existing silvicultural project sites is similarity in functioning between the project sites and silvicultural references.

HYDROLOGIC MODELING OF DRAINED FORESTED WATERSHEDS

Devendra M. Amatya, R. Wayne Skaggs and James D. Gregory [1]

ABSTRACT: The hydrologic water management model DRAINLOB developed for drained forested lands was tested on three watersheds with loblolly pine (Pinus taeda L.) vegetation over a two-year calibration period and a three-year treatment period. Modifications in the interception and ET subroutines improved predictions of daily water table elevations and drainage outflow volumes. Predictions of water table elevations were within 10 to 13 centimeters of measured elevations during the calibration period. Drainage outflow volumes were underestimated by 0.5 to 11.0 percent in comparison to measured outflow volumes.

Testing of the model with three years of data under controlled drainage showed good agreement with observed data. Water table elevations were predicted within 10 to 14 centimeters and the average absolute deviation in daily drainage volumes rates was less than 0.58 millimeters/day. In comparison with observed data, DRAINLOB accurately predicted drainage for watershed 1 (free drainage) and for watershed 3 (controlled drainage). Overestimation of drainage for watershed 2 was attributed to underestimation of ET and seepage when the water table was held high.

Model predictions of time distribution of daily drainage outflow volumes (flows) occurring more than 90 percent of the time were in good agreement with observed data for the calibration period. But predictions for higher flows were not as accurate. For the treatment period, however, the predictions of time distribution of flows of less than 5 millimeters/day, which occurred 99 percent of the time, were accurate for watershed 1 under free drainage and satisfactory for watersheds 2 and 3 under controlled drainage. The consistent overprediction of flows in watersheds 2 and 3 under controlled drainage was attributed to underestimation of ET and errors in data due to periods of weir submergence. The model predicted smaller peak flows and reduced frequency of larger events for watersheds under controlled drainage. A correlation coefficient between 0.77-0.80 was found between observed and predicted monthly total drainage volumes for three watersheds. The predicted mean annual drainage outflow volume for a five-year period (1988-92) was in excellent agreement with observed data.

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INTRODUCTION

Drainage is needed on many wetland forest sites to permit silvicultural practices (bedding, planting, harvesting) without soil drainage and to improve growing conditions for trees. Approximately 1 million hectares of plantation pine in the coastal plain region of the southeastern United States are drained to improve soil trafficability for harvesting and planting operations and to improve soil water conditions for tree establishment and growth (Hughes, 19882). Klaiwitter & Young (1965) determined that the yield from loblolly pine (Pinus taeda L.) on wet pond pine (Pinus serotina michx.) sites in North Carolina can be doubled with good water management including minor drainage to remove excess water.

Several authors have emphasized the importance of good water management to provide the necessary drainage for forest production while conserving water and minimizing detrimental effects downstream (Allen et al., 1990; Campbell & Hughes, 1980; Klaiwitter, 1969; McCarthy, 1990; Terry & Hughes, 1978). Past research in agricultural water management has shown that water can be conserved and both drainage rates and pollutant loads can be reduced by the use of controlled drainage (Deal et al., 1986; Doty et al., 1985; Konyha et al., 1988b; Parsons et al., 1987; Skaggs, 1980). Water table control practices are equally applicable to silviculture, and controlled drainage has been rapidly accepted in the forest industry over the past 15 years. Hughes (1982) reported that artificial drainage of a managed forested wetland, combined with ater management using flashboard risers, provides a diminished, buffered and more uniform release of discharge than either the natural forest or annual agricultural crops.

The hydrologic water balance in a drained wetland forest is difficult to quantify because of the complex inter-relationships among precipitation, infiltration, evapotranspiration, interception, runoff, drainage, water table osition, and soil water distribution and because the natural watersheds are poorly drained. The use of controlled drainage during part or all of the year further complicates the hydrologic and water quality impacts, both at the field edge and on a watershed scale.

In order to quantify the interactions and cumulative impacts of the many processes and parameters affecting hydrology and water quality, researchers have developed hydrologic simulation models. When successfully developed and tested, such models can be used to identify combinations of practices that will enhance productivity and reduce environmental impact (Beasley et al., 1989; Chescheir et al., 1990; Deuver et al., 1988; Guertin et al., 1987; Hammer et al., 1986; Heatwole, et al., 1987; 1988; Konyha et al., 1988a, 1988b; McCarthy, 1990; Parsons et al., 1987; Skaggs, 1980; Thomas et al., 1986).

Of lesser importance to wise management of lands, but important from a regulatory and legal perspective, is the ability of models to predict water table depths and the effects of water management practices on those depths. This means that models could be used to determine objectively whether minor drainage or other water management or cultural practices cause lands to satisfy or not satisfy legal criteria for wetlands. The ability to simulate the performance of a system over long periods (e.g. 20 to 40 years) would allow examination of the effects of water management practices under the wide variation of weather conditions that occur in nature.

A model (DRAINMOD) for predicting the effects of drainage practices on outflow from field scale areas was developed by Skaggs (1978, 1980) for agricultural lands. McCarthy (1990) made modifications in subsurface drainage, rainfall interception, and evapotranspiration components of DRAINMOD to describe the hydrologic processes in a drained loblolly pine plantation. McCarthy & Skaggs (1991a) modified the subsurface component in DRAINMOD to predict effects of lag time, bank storage, and water table shape on drainage under boundary conditions characteristic of silvicultural drainage. Since evaporative loss of

intercepted rainfall may also significantly alter the water balance of a forested watershed, an interception component was added and the evapotranspiration (ET) subroutine in DRAINMOD was modified using the Penman-Monteith method to improve prediction of these components. Analyses using the modified model (DRAINLOB) showed that controlled drainage could be used to reduce drainage water and improve soil water conditions for tree growth.

While the model DRAINLOB was tested for conventional drainage on the three experimental watersheds (Amatya, 1993; McCarthy, 1990; McCarthy et al., 1992), it has not been thoroughly tested and verified for controlled drainage scenarios in forested wetlands. The main purpose of the research reported here is to study the effects of different water management treatments on the hydrology of forested wetlands and to use the results of these experiments to test the validity of the model DRAINLOB (McCarthy, 1990) for various controlled drainage treatments. Water management treatments consisted of controlled drainage practices with weirs in open ditches set at different levels for different periods of time based on the objective of the treatment. Testing and validation of DRAINLOB for modeling the hydrology of drained forested lands will concentrate on its application to evaluate the effects of controlled drainage on the total water balance, water table elevations, total watershed outflow, and drainage outflow rates over time.

OBJECTIVES

The study had three objectives:

(1) Test and verify the simulation model DRAINLOB with five years (1988-92) of data for conventional (free) drainage.
(2) Test and verify the model with three years (1990-93) of data for controlled drainage.
(3) Apply the model to evaluate the effects of various water table management scenarios (controlled drainage practices).

METHODOLOGY

Field measurements were conducted on the Carteret 7 research site, which is located on a large, drained loblolly pine plantation on flat, poorly drained lands owned and operated by Weyerhaeuser Company in Carteret County, North Carolina (Figure 1). Instrumentation of the research site and the experimental methods used on this intensively managed loblolly pine plantation are described briefly below. The reader is referred to Amatya (1993) and McCarthy et al., (1991b) for a detailed description of the site and methods. The research site consists of three artificial experimental watersheds, each about 25 hectares in size. It is characterized by flat, shallow water table soils. The soil is a hydric series, Deloss fine sandy loam (fine-loamy mixed, Thermic Typic Umbraquult). Each watershed was drained by four 1.4 to 1.8 meter deep lateral ditches spaced 100 meters apart (Figure 1). Three rectangular plots located in each watershed were used to collect data on soil, hydrology and vegetation parameters (Figure 1).

Total rainfall was collected with a tipping bucket rain gage in an open area on the west side of each watershed (Figure 1). Air temperature, relative humidity, wind speed and net radiation were collected on an hourly basis on-site. When data were missing, daily values obtained from the weather station at Cherry Point Marine Corps Air Station, North Carolina were used to simulate hourly data as suggested by McCarthy (1990).

An adjustable height 120o V-notched weir, located at the outlet of each watershed, allowed control and measurement of drainage outflow. Water levels were continuously recorded upstream of each weir. An

additional recorder was placed downstream from the weirs to determine if weir submergence occurred and to estimate flows in that event. A pump was installed downstream from all three watersheds on the main roadside collector ditch in January, 1991 to prevent weir submergence during larger events. Monthly measured rainfall and drainage outflows for three watersheds for a five year (1988-92) period are presented in Table 1.

Three experimental plots were designated in each watershed for collecting data on soils, hydrology and vegetation. Soil water table elevations were measured by continuous recorders in wells in two plots midway between the field ditches for each watershed. Water table elevations in transect wells across the watershed were measured periodically to determine the shape of the water table and to calculate the change in soil water storage over periods of time. Soil water content in the unsaturated zone above the water table was measured periodically with a neutron meter. Water levels in ditches adjacent to the watershed boundaries were measured periodically to compute lateral seepage.

Saturated lateral hydraulic conductivity (Ks) of the Deloss fine sandy loam soil was measured using the auger-hole method in several locations in these watersheds. Hooghoudt's equation and the nonlinear Boussinesq equation were also used to calculate Ks from drain flow and water table measurements.

Loblolly pine stand was planted in 1974 at a 1.74 meter by 2.74 meter spacing (2100 trees/hectare), following harvest of a natural stand of loblolly and pond pine. Data on mean stocking, basal area, timber volume, height and volume increments of the stands for the five year period are presented elsewhere (Amatya, 1993). Prior to a commercial thinning in October, 1988, canopy closure of the 15-year old loblolly pine stand was about 85 percent based on an ocular estimate and basal area was 32.6 m2/hectare. After the thinning, canopy closure was reduced to approximately 50 percent and basal area to 16.1 m2/hectare. Leaf Area Index (LAI) for each year was estimated from litterfall collected monthly from eight 1.2 meter diameter litter traps, randomly placed within each of the three plots in the watershed. In August 1988, the prethinned stand was estimated to have an all-sided LAI of 8.3. Stomatal conductance was measured approximately every three weeks in each year with a porometer. Measurements of water table depth at the transect wells, neutron meter readings, and foliage samples were also taken at the time of porometer readings on plots 1, 3, 4, 6, 7, and 9 (Figure 1).

A rainfall interception study was conducted on the site in 1987 and again in 1989 to quantify through fall precipitation, stemflow, and canopy storage capacity. For each rainfall event, 13 randomly placed buckets were used to collect through fall precipitation on each watershed. In 1989, the through fall sampling was changed to 20 buckets on both watersheds 1 and 3. Stemflow was collected on 10 sampled trees. These measurements were done in one plot of each watershed. Evapotranspiration as the sum of dry transpiration and soil evaporation was computed as the residual in the measured water balance. Deep seepage was assumed to be negligible and was included in the ET term.

Study design and treatments:

Calibration took place between February 2, 1988 and March 19, 1990 when all three watersheds were treated identically. During this period, the weir depths were varied among depths of 1.0 meter, 0.8 meter and 0.6 meter from the ground surface in all watersheds at the same time. This was done with the objective of describing the hydrology of the system and the hydrologic response to weir elevation (Weyerhaeuser unpublished data).

From March 19, 1990 to March 16, 1993, three water level management or controlled drainage treatments were applied as follows:

(A) Watershed 1. Free drainage (Control). The weir level (bottom of notch) at the ditch outlet was set at a depth of 1.0 meter below the mean surface elevation of the watershed for the duration of the study.

(B) Watershed 2. Higher weir levels (shallower depth) during growing season to conserve water to promote tree growth. Weir depth at the ditch outlet was set at 1.0 meter from December 1 to June 15 and at 0.6 meter from June 16 to November 30.

(C) Watershed 3. Raised weir levels (shallower depth) during spring months to reduce drainage outflows and minimize downstream impacts. Weir depth was set at 1.0 meter from December 1 to March 15, at 0.4 meter from March 16 to June 15 and at 0.8 meter from June 16 to November 30.

Model simulation analyses presented herein use measurements for approximately three years (March, 1990 to February, 1993), concentrating on the watershed performance under controlled drainage conditions.

Model Description:

DRAINLOB (McCarthy, 1990) is a version of DRAINMOD (Skaggs, 1978; 1980) modified for forested watersheds. The modifications were made in subsurface drainage, and the interception and evapotranspiration components of DRAINMOD. DRAINMOD simulates the response of the soil water regime between the ditches to different combinations of surface and subsurface water management practices. The model computes the water balance midway between parallel ditches as

$$\Delta Va = D + ET + DS - F$$

where ΔVa = change in air volume or soil water storage (cm) in the profile, D is the drainage (cm), ET is evapotranspiration (cm), DS is deep seepage (cm) and F is infiltration (cm).

The amount of runoff and storage on the surface is computed from a water balance at the soil surface for each time increment which is written as

$$P = F + \Delta S + RO$$

where P is the precipitation (cm), F is infiltration (cm), ΔS is the change in volume of water stored on the surface (cm), and RO is runoff (cm) during time Δt.

For the modified forestry version, DRAINLOB, McCarthy (1990) and McCarthy & Skaggs (1991a) developed a simplified model for predicting drainage rates under the changing boundary conditions characteristic of forested watersheds drained by widely spaced parallel ditches. The drainage rate was computed by using numerical solutions of the nonlinear Boussinesq equations based on average water table shape between the midpoint and the ditch. By doing so, the drainage flux due to the entire range of water table positions including transitions from ponded water conditions to an elliptic water table profile, bank storage and lag time effects are addressed in DRAINLOB. The method also takes into account the ET effects on drainage flux. Kirkham's equation was used for predicting subsurface drainage during ponded water conditions, as in DRAINMOD.

Since, evaporative losses of intercepted rainfall generally comprise 15-30 % of the forest water balance, rainfall interception was incorporated into the modified model. The volume of forest canopy interception loss was calculated by the method of Rutter et al., (1972) described by Amatya (1993) and McCarthy (1990).

According to this method, the canopy water balance was written as $I = \Sigma Ri - \Sigma Hi$, where I = total canopy interception loss (cm), Ri = total rainfall for time period i (cm) and Hi = total through fall precipitation for time period i (cm). In the water balance for DRAINLOB, wet canopy evaporation is computed separately from evapotranspiration (ET). Evaporative losses due to rainfall interception are first allowed to occur based on the potential wet canopy evaporation rate calculated by the Penman-Monteith method with zero canopy resistance. When the canopy storage becomes dry, then transpiration is allowed to occur.

Because of the large surface storage capacity of the bedded plantation, the surface runoff component was assumed to be negligible, making through fall precipitation equal to the total infiltration volume.

Evapotranspiration (ET) was defined as the sum of dry canopy transpiration and soil evaporation. Dry canopy transpiration was computed by the Penman-Monteith method with a stomatal conductance function (Amatya, 1993; McCarthy, 1990). The hourly potential transpiration calculated by Penman-Monteith method was directly used in the model. For periods when wet canopy evaporation is zero, the model, as in DRAINMOD, allows the transpiration losses to occur at the potential rate as long as the upward flux can satisfy the PET demand. When the upward flux becomes smaller than the potential rate, the deficit is then supplied by soil water from the root zone. This creates a dry zone which subsequently increases in depth as ET continues. When the dry zone depth becomes equal to the rooting depth, transpiration is limited by soil water conditions and is set equal to the upward flux. Similarly, soil evaporation rate is limited by the potential evaporation rate, leaf area index (LAI) and upward flux from the water table.

The procedures for modeling the components of soil drainage, interception and evapotranspiration for the experimental watersheds have been explained in detail elsewhere (Amatya, 1993; McCarthy, 1990; McCarthy et al., 1992).

The new water balance for DRAINLOB model was recomputed as follows:
$\Delta Va = D + I + ET - R$
where, I = evaporative losses of intercepted rainfall (cm), ET = sum of dry transpiration and soil evaporation (cm), D = soil drainage (cm), R = total rainfall (cm) and ΔVa = change in air volume or soil water storage (cm). R - I is infiltration, F. Deep and lateral seepage were not considered in the model.

Model Testing:

The modified model was tested using two years of data (1988-89) for the calibration period and three years of data under controlled drainage conditions initiated in Spring, 1990. After testing with the available data for three years of treatment, the model was used to evaluate effects of various water table management scenarios (controlled drainage practices) on the hydrology of the pine plantation. The predicted hydrologic processes in watersheds 2 and 3 under controlled drainage were compared to those for conventional (uncontrolled) drainage in watershed 1.

Procedures for Model Testing:

To test the model, observed data for the calibration and treatment periods were compared with model predictions of:

- water balance components;
- daily and daily cumulative drainage outflow volumes;

- daily water table elevations;
- daily flow duration curves;
- monthly and annual drainage outflow volumes.

The average absolute differences between predicted and observed daily outflow volumes and daily cumulative outflow volumes were used for assessing model predictions of drainage outflows. The average absolute differences between predicted and observed daily water table elevations were used to examine the model reliability in predicting water table depths. Coefficient of determination and slope were used to compare monthly observed and simulated drainage outflow volumes. Distributions of observed and simulated monthly drainage outflow volumes were examined. Similarly, percent time of occurrence of flows larger than 5 millimeters/day, and the size of flows that occurred more than 90 and 99 percent of the time were used to compare observed and predicted daily flow duration relationships.

RESULTS AND DISCUSSION

Drainage outflows and water balance components:

Water balance components predicted by the model were compared with field measurements for all three watersheds during the calibration period, February 2, 1988 to March 19, 1990 (Table 2). The drainage volume predicted by DRAINLOB for watershed 3 agreed closely with the observed data. The drainage volume was underestimated by 5.3 percent for watershed 1 and by 11.8 percent for watershed 2. The model overpredicted ET for watersheds 1, 2, and 3 by 8.8, 10.1, and 3.9 percent respectively. Some of these overpredictions may be due to losses by lateral seepage that were not considered by the model.

Some errors in the observed drainage outflow volumes for all watersheds may have been caused by weir submergence during very large rainfall events that occurred during March, April, September, October, and December of 1989 (Amatya, 1993). During September and December of 1989, with the same weir treatment in all watersheds, deviations between observed and predicted outflow volumes were greater for watersheds 1 and 2 than for watershed 3. The presence of positive error in the discharge measurements is clear in December, 1989 when measured drainage volume was greater than and equal to the observed rainfall in watersheds 1 and 2, respectively (Table 1).

Figures 2, 3 and 4 show observed rainfall, measured and predicted daily drainage outflow volumes and daily cumulative drainage outflow volumes, and observed and predicted water table elevations with corresponding weir levels during the calibration period for watersheds 1, 2 and 3, respectively. Model predictions of daily drainage volumes and daily cumulative volumes were in better agreement with observed data for watersheds 2 and 3 than in watershed 1 in 1988. But it is difficult to explain these discrepancies due to some weir submergence that occurred in late 1988. Also, the timing of thinning between August to October in these three watersheds might have had an effect on predicted drainage outflows. Because 1989 was a wetter year than 1988, weir submergence resulted in larger errors in measured drainage outflow volumes in all watersheds.

Lateral seepage was not considered in DRAINLOB. It was, however, included in the observed drainage outflows and water balance. Table 3 shows the difference between measured and DRAINLOB simulated drainage outflows and water table depths. As compared to observed cumulative drainage and seepage, the DRAINLOB simulation underestimated cumulative drainage by 5.5, 11.8 and 0.1 percent for watersheds 1, 2, and 3, respectively. The average absolute differences between predicted and measured daily cumulative

drainage volume were 72.1 millimeters (7.8 percent), 50.4 millimeters (5.6 percent), and 44.7 millimeters (5.2 percent) for watersheds 1, 2, and 3, respectively. The average absolute difference between predicted and observed daily drainage volumes were less than 0.79 millimeters/day for all watersheds. Plots of predicted water table elevations were in close agreement with the observed data. Average absolute differences between measured and predicted water table elevations were 10.5, 10.7, and 13.5 centimeters for watersheds 1, 2, and 3 respectively. This represents about a 50 percent reduction in the errors reported by McCarthy et al., (1992). Table 3 and the plots of drainage outflows and water table depths in Figures 2 to 4 showed that the model predictions for the calibration period improved significantly as compared to the data published earlier by McCarthy et al., (1992).

DRAINLOB simulated water balance results are compared in Table 4 with observed data for watershed 1 (free drainage) and watersheds 2 and 3 (controlled drainage) for the 1990-93 treatment period. Measurements for the three watersheds show significant reductions in drainage outflow volumes for controlled drainage (watersheds 2 and 3) as compared to watershed 1 which had free drainage. The impact of the treatment predicted by DRAINLOB for watershed 2, however, was not as great as the observed impact. Predicted drainage volume was in excellent agreement with observed data for watersheds 1 and 3. However, drainage volume was overpredicted by 38 percent for watershed 2 under the controlled drainage treatment designed to enhance tree growth. Comparison of observations and model estimates for other components shows that ET was overpredicted by the model for watersheds 1 and 3 and underestimated for watershed 2. The amount of overpredictions match fairly well with the amount of estimated seepage in the measured water balance. This seepage was not taken into account by the model. Taking the measured seepage into account, the overprediction of drainage volume in watershed 2 was most probably due to the underestimate of ET and seepage when water tables were held higher during the growing season. Measurements showed that the higher weir elevations in watershed 2 resulted in 344 millimeters less drainage than from watershed 1. This overestimate of drainage was consistent with an earlier study by Whitehead et al., (1991) who reported the ET and seepage as major possible sources of errors in modeling a Pinus Radiata catchment.

The drainage volume measured during January, 1991 may be somewhat inaccurate for all watersheds because weirs were submerged when the road-side collector ditch outlet was blocked for pump installation in the outlet ditch (Amatya, 1993). Watershed 3 is at the lowest elevation and had the longest period of weir submergence. This led to overestimation of the drainage outflow volume for watershed 3 as compared to watersheds 1 and 2 when all three were under the same free drainage conditions.

Figures 5, 6 and 7 show rainfall, observed and predicted daily drainage outflow volumes, cumulative drainage outflow volumes, and observed and predicted water table elevations with corresponding weir levels for watersheds 1, 2 and 3 respectively during the treatment period (1990-93). The period of larger weir submergence in late March and early April, 1990 is omitted in this comparison. As stated earlier, some errors in daily drainage outflow volumes and daily cumulative drainage outflow volumes were observed during the weir submergence periods in late March, 1990 and January, 1991 with the largest discrepancies in watershed 3. Therefore, the comparison for watershed 3 was done only from February 01, 1991 (Figure 7).

Differences between observed and predicted daily drainage outflow volumes, daily cumulative drainage outflow volumes, and water table depths are presented in Table 5. DRAINLOB predicted total drainage volumes for the 3-year treatment period of 1369, 1240, and 1087 millimeters as compared to measured cumulative drainage volumes of 1357, 896, and 1086 millimeters for the three watersheds. Average absolute differences between predicted and measured daily cumulative drainage volumes were 23.0 millimeters (1.7 percent), 103.0 millimeters (11.4 percent), and 25 millimeters (2.3 percent) for watersheds 1, 2, and 3

respectively. The absolute difference in watersheds 1 and 3 were very small indicating the accuracy of model predictions. The larger prediction error in watershed 2 was most likely due to overestimation of drainage volume as a result of underpredicting ET and neglecting seepage during the growing season when the weir was elevated. The average absolute differences between predicted and observed daily drainage outflow volumes were 0.45, 0.49, and 0.58 millimeters/day for watersheds 1, 2 and 3, respectively. These results represent closer agreement between predicted and observed values than was obtained for the calibration period. One of the reasons is evident because of more reliable drainage outflow data obtained after pump installation in January, 1991. Similarly, the computed average absolute differences between predicted and observed daily water table elevations were 13.6, 11, and 13.9 centimeters for watersheds 1, 2, and 3, respectively. These results are comparable with those obtained for the calibration period.

Impacts of the controlled drainage treatment on drainage outflows for watershed 3 were accurately predicted by DRAINLOB in all three years. There was a much greater difference between predicted and observed results for the controlled drainage treatment designed to promote tree growth in watershed 2. This was most likely due to underestimation of ET and seepage during the summer. ET demands during the spring period, when the weir was elevated to its highest level in watershed 3 than in watershed 2, were much lower than during the summer when watershed 2 was subjected to controlled drainage. Apparently the model did not totally account for the increased ET resulting from controlled drainage during the summer. This effect plus neglecting lateral seepage caused the model to overpredict drainage for watershed 2.

Flow Duration Analyses :

Observed and predicted flow duration curves of daily drainage outflow volumes (flows) for the calibration and treatment periods for all watersheds are illustrated in Figures 8 and 9 respectively. The zero daily flows predicted for more than 60 percent of the time for the calibration and more than 65 percent of the time for the treatment periods were in exact agreement with observed data for all watersheds. The model accurately predicted the smaller flows (less than about 5 millimeters/day), which occurred more than 90 percent of the time in all watersheds for the calibration period. However, the model tended to underpredict flows in the range of 5 to 20 millimeters/day for watersheds 1 and 2 and 5 to 10 millimeters/day for watershed 3 respectively. Overpredictions were found for flows higher than 20 millimeters/day. Predictions of flows for more than 99 percent of time in watershed 3 were in closer agreement with observed data for the calibration period. Much of the differences between predicted and observed flows greater than 10 millimeters/day were attributed to errors in data due to submerged weirs during 1988-90.

For the treatment period, model predictions of the time distribution of daily flows in watershed 1 under free drainage were accurate throughout the range of daily flow volumes. There were some underpredictions for the largest daily flows that occur less than 1 percent of time. However, the predicted daily flows were consistently higher than the observed data for the entire range of flows (excluding time of zero flows) for watersheds 2 and 3. However, the comparisons show good agreement in timing between the observed and predicted flows. The difference between predicted and observed frequency of small daily flows less than 5 millimeters/day (including zero flows) occurring about 98 percent of the time were relatively smaller for watershed 2 than for watershed 3. But the prediction errors for higher daily flows occurring less than 1 percent of time were found to be higher for watershed 2 than for watershed 3. Some of these errors in predicting frequency of high daily flows may be attributed to errors in predicting ET as affected by antecedent soil water conditions in watershed 2 and 3 when weir levels were elevated for controlled drainage. Comparing observed frequencies of daily flows among the three watersheds shows that flow occurred for a smaller percent of time in watersheds 2 and 3 than in watershed 1 and that flows of the same frequency were always smaller in watersheds 2 and 3

than in watershed 1.

Monthly and Annual Drainage Outflows:

The reliability of DRAINLOB predictions of drainage outflow volumes was examined by comparing the predicted total monthly drainage volumes with the observed ones (Figure 10). With a coefficient of determination R2 nearly equal to 0.80 and slope close to unity, the predictions were in better agreement for watersheds 1 and 3 than for watershed 2. The larger error in watershed 2 was mainly due to overpredictions of drainage outflow by the model during the growing season. Similarly, a very large measured outflow in watershed 3 due to weir submergence during pump installation was plotted as an outlier in Figure 10. Comparison of observed and predicted annual drainage outflows for a five-year period for three watersheds is illustrated in Figure 11. Predicted annual drainage for all watersheds compared well with observed data. Since 1990 was the driest year, the errors in predictions of annual drainage were almost negligible in all watersheds. But in wetter years of treatment, overprediction of drainage occurred in watershed 2 due to underestimation of ET and seepage.

The predicted flow duration curves of daily flow volumes for the three watersheds for the treatment period are presented in Figure 12. Throughout most of the range of daily flow volumes, flows were predicted to occur slightly more frequently in watershed 1 with free drainage in comparison to watersheds 2 and 3 with controlled drainage. Watershed 3 was predicted to have lowest drainage rates for the extreme conditions (highest daily flows) compared to the two other watersheds. As expected, the magnitude and frequency of predicted high flow rates were reduced by controlled drainage. Results in Figure 13 show the comparison of observed and predicted 5-year mean annual drainage for three watersheds. The results were in excellent agreement for watersheds 1 and 3; the 11 percent overestimate of drainage in watershed 2 was probably due to underestimation of ET and seepage during controlled drainage in 1991 and 1992. The comparison also shows that the long term average annual drainage volumes do not vary substantially among the treatments. However, three years of limited data on treatment may be inadequate to make such conclusions. An important point also in interpreting these data is that within each year, there is a significant time period that encompasses much of the total time of above zero drainage outflows wheen the weirs are at 1 m depth in all three watersheds.

SUMMARY AND CONCLUSIONS

DRAINLOB, a version of DRAINMOD modified by McCarthy (1990) for drained forest wetlands, was retested using two years of data from the calibration period (1988-1989) for three experimental watersheds in Carteret county, NC. Modifications in leaf area index (LAI), canopy storage capacity, the aerodynamic resistance term in the Penman-Monteith wet canopy evaporation, the canopy growth function, and the stomatal conductance submodel substantially improved the model simulations of drainage outflows and daily water table elevations as compared to the results published earlier (McCarthy, 1990; McCarthy et al., 1992). The modified model predicted water table elevations within 13 centimeters and daily drainage volumes within 0.79 millimeters/day of observed values. Some discrepancies in outflows were due to flows during weir submergence periods in the wet year of 1989.

The model was further tested with three additional years of data for the treatment period (1990-92). Watersheds 1, 2 and 3 were operated with different weir levels in the outlet ditch: (1) free drainage; (2) weir raised in summer to provide increased soil water for tree growth, and (3) weir raised in spring to reduce offsite impacts. Effects of the controlled drainage in watersheds 2 and 3 were compared with results from

watershed 1, which was in free drainage and treated as the baseline condition. The predicted drainage outflows for watersheds 1 and 3 were in excellent agreement with observed data. The 38 percent overestimate of drainage calculated for the observed data in watershed 2 was mainly attributed to underestimation of ET and seepage during the growing season when the weir was held higher than in the other treatments.

In comparison to watershed 1, the controlled drainage treatment in watershed 3 had a greater predicted impact on drainage outflow volumes than did the treatment in watershed 2. Discrepancies in predicted and observed drainage outflow volumes were most likely due to underestimation of ET during the growing season in watershed 2 and overestimation of drainage volume in watershed 3 during pump installation. Average absolute deviations in measured and the model predicted daily drainage volumes were less than 0.58 millimeters/day for all watersheds. The errors in drainage volumes were reduced when weir submergence periods were excluded for watersheds 2 and 3.

Model predictions of the time distribution of daily outflow volumes (flows) for the calibration period were in close agreement with observed data. The model, used to evaluate the effects of controlled drainage on drainage outflow volumes and their time distribution, accurately predicted daily flows less than 8 millimeters/day for watershed 1 except for some periods when the weirs were submerged and flow measurements were uncertain. However, the model consistently overpredicted the frequency of the larger flows in watersheds 2 and 3. These overpredictions were attributed to underprediction of ET and lateral seepage losses. The model predicted smaller maximum daily flows and reduced frequency of larger events for watersheds under controlled drainage.

The relationship between predicted and observed monthly drainage outflow volumes had a coefficient of determination (R2) close to 0.80 for all watersheds. Predicted annual drainage outflows were also in good agreement with observed data except for watershed 2 where drainage was overpredicted. However, the good agreement between observed and predicted daily events confirms that the overeprediction was most likely due to errors in the components of evapo-transpiration and seepage. These results were consistent with the study reported by Whitehead and Kelliher (1991). The results also indicate that data for three years of treatment is inadequate to draw conclusions about the long-term effects of controlled drainage treatments on annual drainage outflow volumes.

The DRAINLOB model, tested and validated with three years of data from water table treatment, can be used to evaluate the effects of variation in weather patterns, water management, and silvicultural practices on the hydrologic water balance, drainage outflow rates, and their time distribution. These results could then be used to determine the combination of practices for optimum management for tree growth and reduction of offsite impact.

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Table 1. Monthly measured total rainfall and drainage outflow volumes for the 1988-92 period for three watersheds.

Year	Months	Monthly rainfall (mm)			Monthly drainage outflows (mm)		
		WS 1	WS 2	WS 3	WS 1	WS 2	WS3
1988	1	170.81	172.32	171.8	35.59	89.41	42.31
	2	99.62	99.09	98.57	78.79	73.32	82.08
	3	65.05	66.06	65.55	10.09	8.24	14.41
	4	108.25	107.22	107.22	5.46	4.78	10.15
	5	167.68	172.74	172.74	19.89	19.06	33.84
	6	69.63	66.58	65.06	0.04	0.03	0.29
	7	141.25	125.5	115.85	0	0	0
	8	349.04	345.47	349.02	36.98	38.65	30.12
	9	54.92	52.4	52.4	21.93	21.56	26.58
	10	64.53	64.04	64.04	0	0	0
	11	95.54	90.46	90.46	0	0	0
	12	19.35	18.29	18.29	0	0	0
1989	1	100.66	93.04	93.04	0	0	0
	2	81.87	81.35	81.35	7.46	8.24	8.66
	3	202.77	200.7	191.6	92.22	106.31	100.17
	4	181.94	175.87	173.3	101.25	114.24	111.09
	5	67.09	66.59	65.51	11.57	9.93	12.12
	6	129.07	110.27	99.11	0	0	0
	7	212.4	205.29	191.05	11.22	5.67	1.03
	8	73.69	82.34	89.95	0	0	0
	9	397.2	383.66	367.34	126.07	114.92	77.65
	10	184.95	188.52	184.95	82.48	78.39	67.88
	11	73.69	73.72	71.17	48.73	36.99	56.91
	12	170.2	167.16	160.04	176.66	166.94	117.47
1990	1	63.02	61.99	57.92	64.18	57	69.56
	2	61.5	59.97	54.91	25.04	21.4	32.02
	3	166.7	160.61	152.47	51.05	34.95	21.01
	4	122.45	117.37	117.36	77.85	63.11	27.7
	5	99.1	94.51	86.4	16.09	16.5	0
	6	28.46	27.95	23.88	0	0	0
	7	125.56	124.01	117.37	0	0	0
	8	234.72	211.36	173.76	0	0	0
	9	72.67	61.49	56.41	0	0	0
	10	103.15	117.36	117.87	0	0	0
	11	71.15	70.64	68.07	0	0	0
	12	87.43	84.39	82.32	5.81	0.38	0
1991	1	254.57	238.32	219.52	183.24	166.6	259.14
	2	34.06	33.55	28.49	40.93	24.87	47.32
	3	131.05	125.48	110.26	61.92	52.35	35.98
	4	108.74	94.5	90.44	7.32	6.64	0
	5	54.87	52.33	51.33	7.37	6.34	0
	6	79.3	84.39	108.27	0	0	0
	7	260.18	265.26	261.16	0.09	0	0.05
	8	203.56	187.51	195.21	76.68	8.23	53.64
	9	130.54	133.31	115.76	7.55	0	0.13
	10	133.13	131.61	127.76	55.35	8.84	31.54
	11	64.03	54.91	57.7	8.36	0	0
	12	120.92	106.46	112.27	43.47	38.79	44.19
1992	1	195.1	203.46	189.51	178.68	150.82	179.15
	2	75.74	72.17	71.7	52.03	44.91	56.81
	3	159.04	153.45	153.21	75.86	80.95	47.07
	4	45.76	44.75	44.74	8.59	10.0	0
	5	142.2	142.2	133.6	11.80	8.6	0.40
	6	87.9	87.9	88.4	18.9	17.3	0
	7	186.9	186.9	133.6	11.9	2.5	0
	8	236.2	236.2	216.4	80.5	65.6	46.00
	9	174.2	174.2	182.4	19.6	10.7	23.40
	10	77.2	77.7	75.7	38.7	34.2	41.90
	11	166.1	165.6	158.0	53.4	40.5	46.20
	12	72.6	70.6	71.6	46.8	64.8	45.50

Table 2. Measured and DRAINLOB predicted volume of each water balance component for the calibration period, Day 33-809 (Feb 2, 1988 - Mar 19, 1990)

Water balance components	Watershed 1 Measured mm	Watershed 2 Measured mm	Watershed 3 Measured mm	Watershed 1 Predicted mm	Watershed 2 Predicted mm	Watershed 3 Predicted mm
Gross Rainfall :	3272.5	3193.9	3113.0	3272.5	3193.9	3113.0
Interception loss:	548.7	542.8	529.8	548.7	542.8	529.8
Drainage :	930.9	892.2	863.6	882.4	787	859.2
Seepage :	104.3	104.6	56.1	0	0	0
Change in soil water storage :	- 6.5	0.4	-12.5	-4.0	41.2	-19.7
Water balance ET :	1695.1	1653.9	1676.0			
Predicted ET :				1844.0	1821.2	1742.2
Total ET :	2243.8	2196.7	2205.8	2392.7	2364.0	2272.0

Note: Water balance (ET) = Residual term in water balance;
Predicted ET = Predicted transpiration + Predicted soil evaporation;
Total ET = Residual ET + Interception loss or Predicted ET + Interception loss;

Table 3. Differences between measured and DRAINLOB predicted hydrologic parameters for the calibration period (Feb 02, 1988 - Mar 19, 1990).

Hydrologic parameter	Watershed 1	Watershed 2	Watershed 3
DRAINLOB predicted cumulative drainage volume (mm) :	882	787	859
Measured cumulative drainage plus lateral seepage volume (mm) :	1035	997	920
Measured cumulative drainage volume (mm) :	931	892	864
Average absolute differences in daily drainage volume (mm) :	0.79	0.72	0.67
Average absolute differences in daily cumulative drainage volume (mm) :	72.1	50.4	44.7
Average absolute differences in daily water table elevation (cm) :	10.5	10.7	13.5

Table 4. Measured and DRAINLOB predicted volume of each water balance component for the treatment period, Day 809 - 1846 (Mar 19, 1990 - Jan 19, 1993)

Water balance components	Watershed 1	2	3	1	2	3
	Measured			Predicted		
	mm	mm	mm	mm	mm	mm
Gross Rainfall :	4445.7	4333.3	4131.1	4445.7	4333.3	4131.1
Interception loss :	636.3	608.9	605.6	636.3	608.9	605.6
Drainage :	1357.0	896.2	1086.0	1369.0	1240.0	1087.0
Seepage :	108.8	115.3	79.1	0	0	0
Change in soil water storage :	16.3	14.2	13.0	-13.5	-10.6	-27.2
Water balance ET :	2201.3	2559.2	2258.8			
Predicted ET :				2426.8	2483.7	2419.8
Total ET :	2837.6	3168.1	2864.4	3063.1	3092.6	3025.4

Note: Water balance (ET) = Residual term in water balance;
Predicted ET = Predicted transpiration + Predicted soil evaporation;
Total ET = Residual ET + Interception loss or Predicted ET + Interception loss;

Table 5. Differences between measured and DRAINLOB predicted hydrologic parameters for the calibration period (Mar 19, 1990 - Jan 19, 1993).

Hydrologic parameter	Watershed 1	2	3
DRAINLOB predicted cumulative drainage volume (mm) :	1369	1240	1087
Measured cumulative drainage plus lateral seepage volume (mm) :	1592	1151	1254
Measured cumulative drainage volume (mm) :	1357	896	1086
Average absolute differences in daily drainage volume (mm) :	0.45	0.49	0.58
Average absolute differences in daily cumulative drainage volume (mm) :	23.0	103.0	25.0
Average absolute differences in daily water table elevation (cm) :	13.6	11.0	13.9

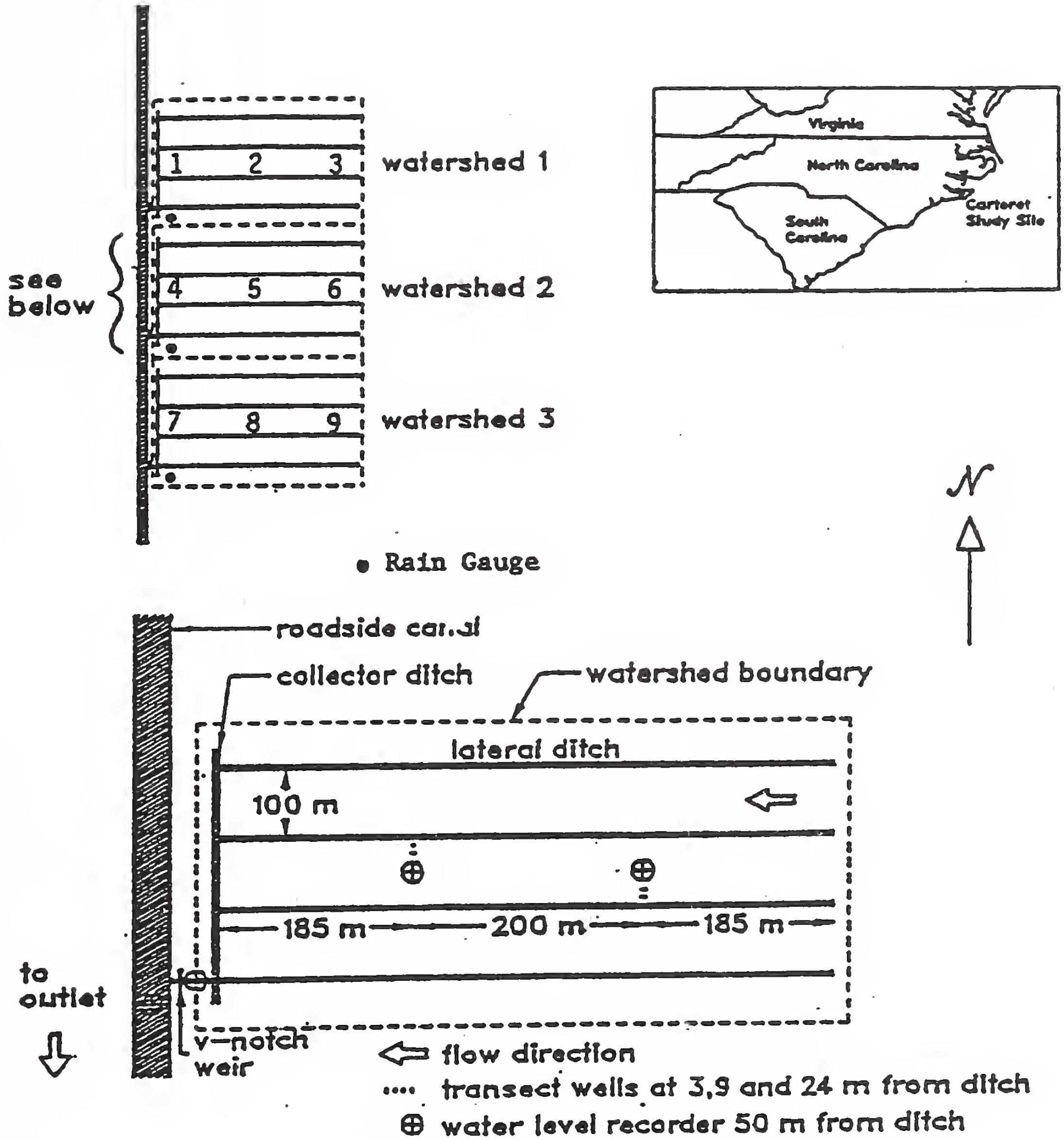


Figure 1. Experimental layout of three watersheds at Carteret 7, NC (After McCarthy, 1990)

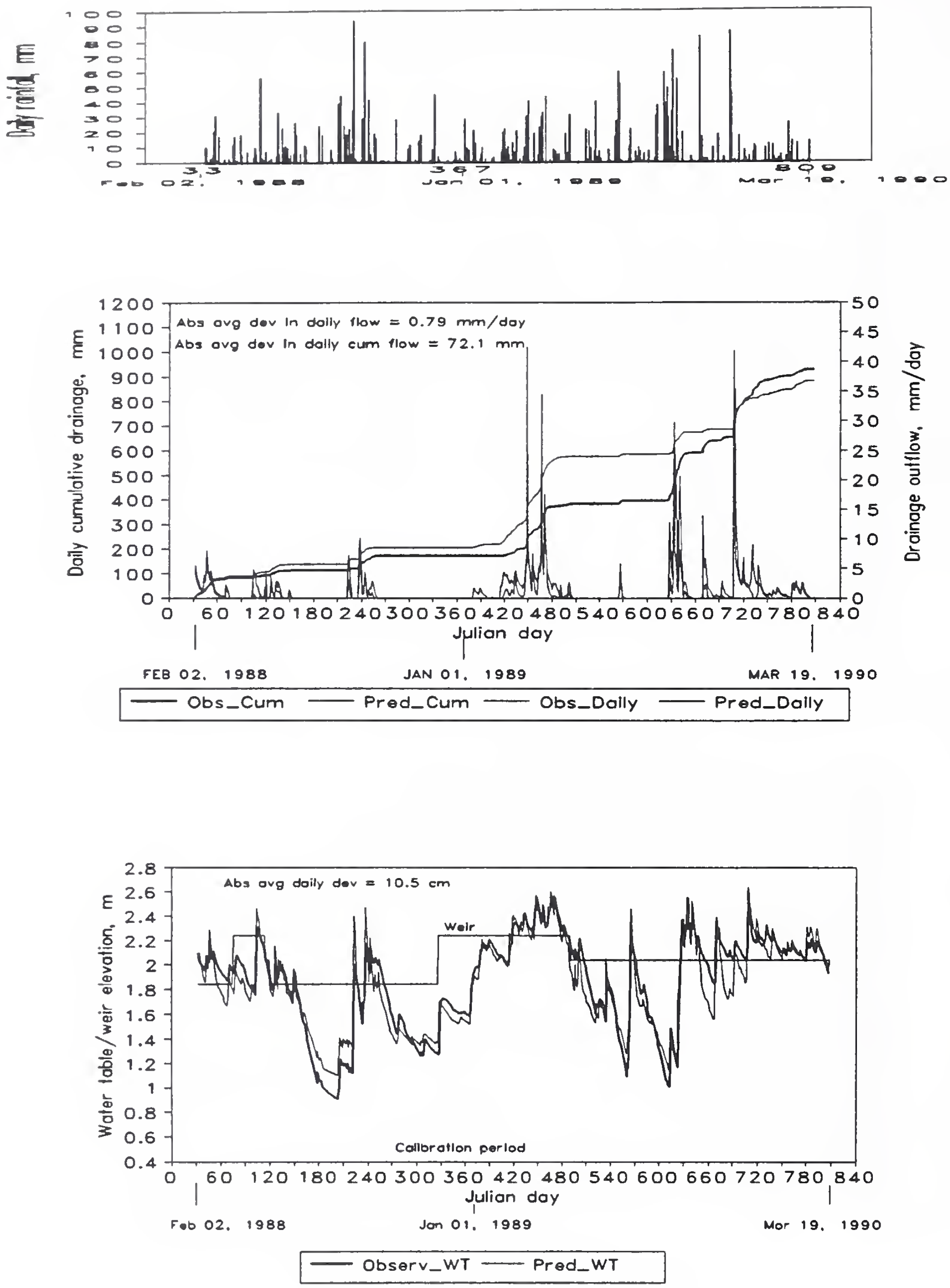


Figure 2. Rainfall (top), predicted and observed daily and daily cumulative drainage volumes (middle) and water table elevations with weir levels (bottom) for watershed 1 for the calibration period (February 02, 1988 - March 19, 1990).

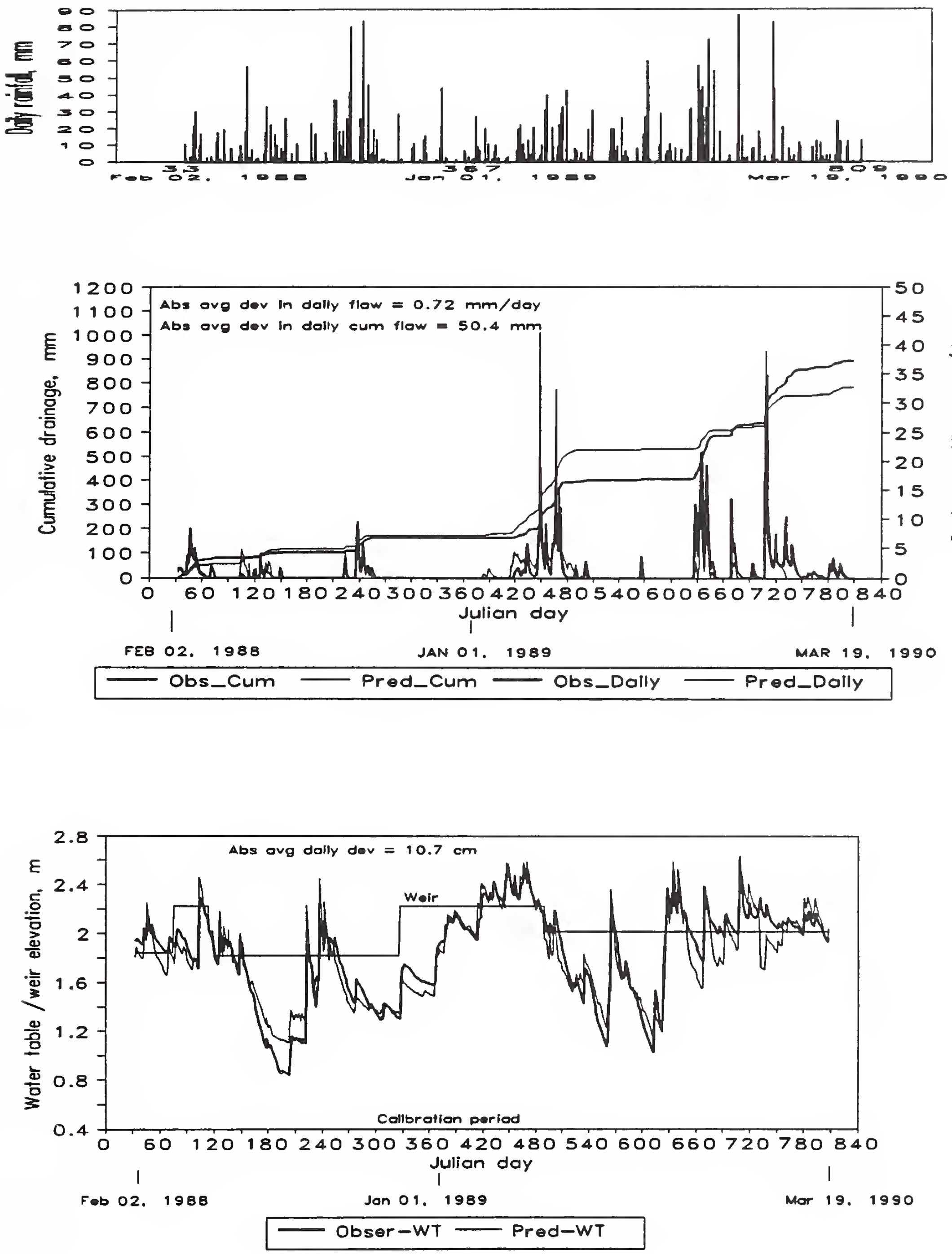


Figure 3. Rainfall (top), predicted and observed daily and daily cumulative drainage volumes (middle) and water table elevations with weir levels (bottom) for watershed 2 for the calibration period (February 02, 1988 - March 19, 1990).

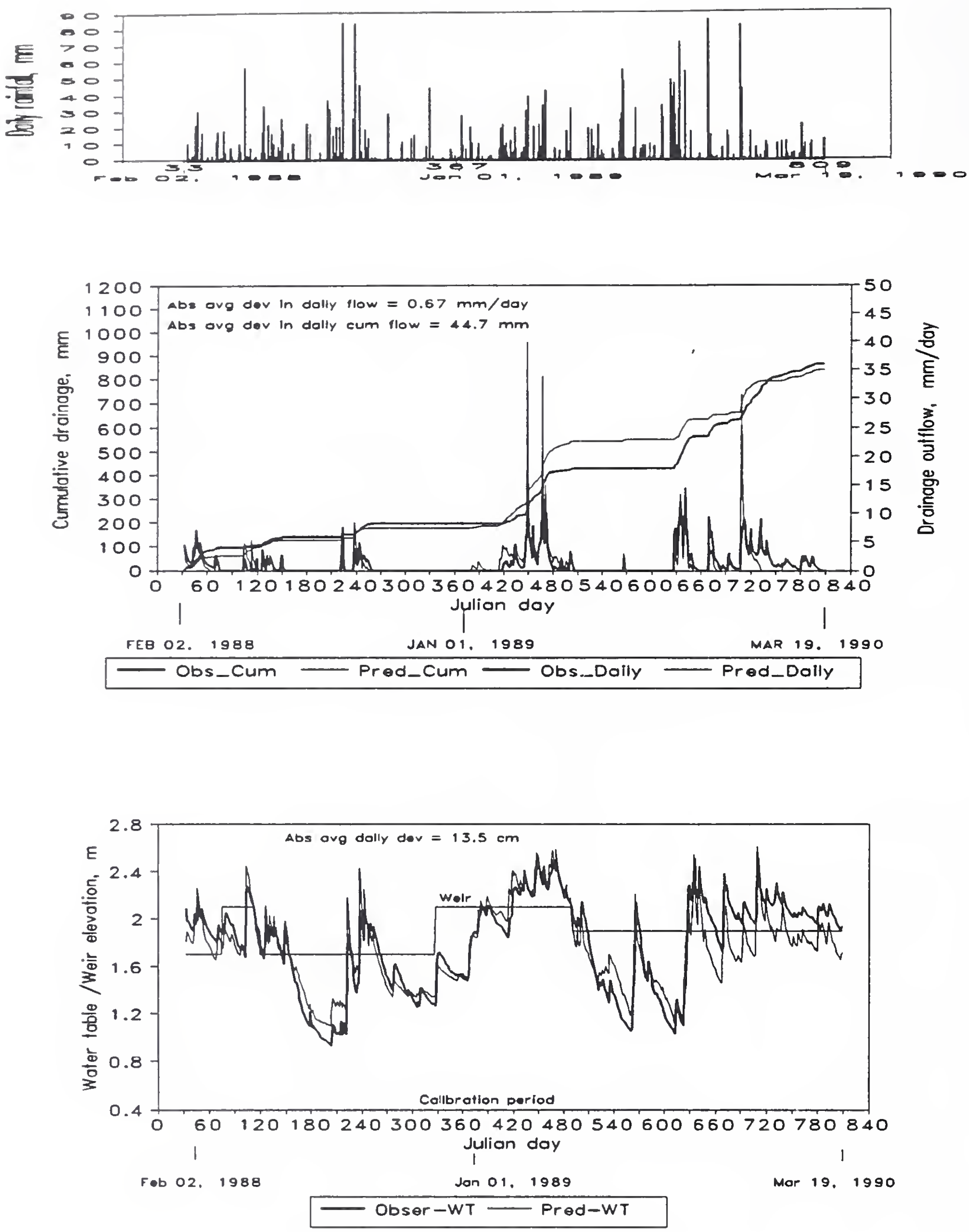


Figure 4. Rainfall (top), predicted and observed daily and daily cumulative drainage volumes (middle) and water table elevations with weir levels (bottom) for watershed 3 for the calibration period (February 02, 1988 - March 19, 1990).

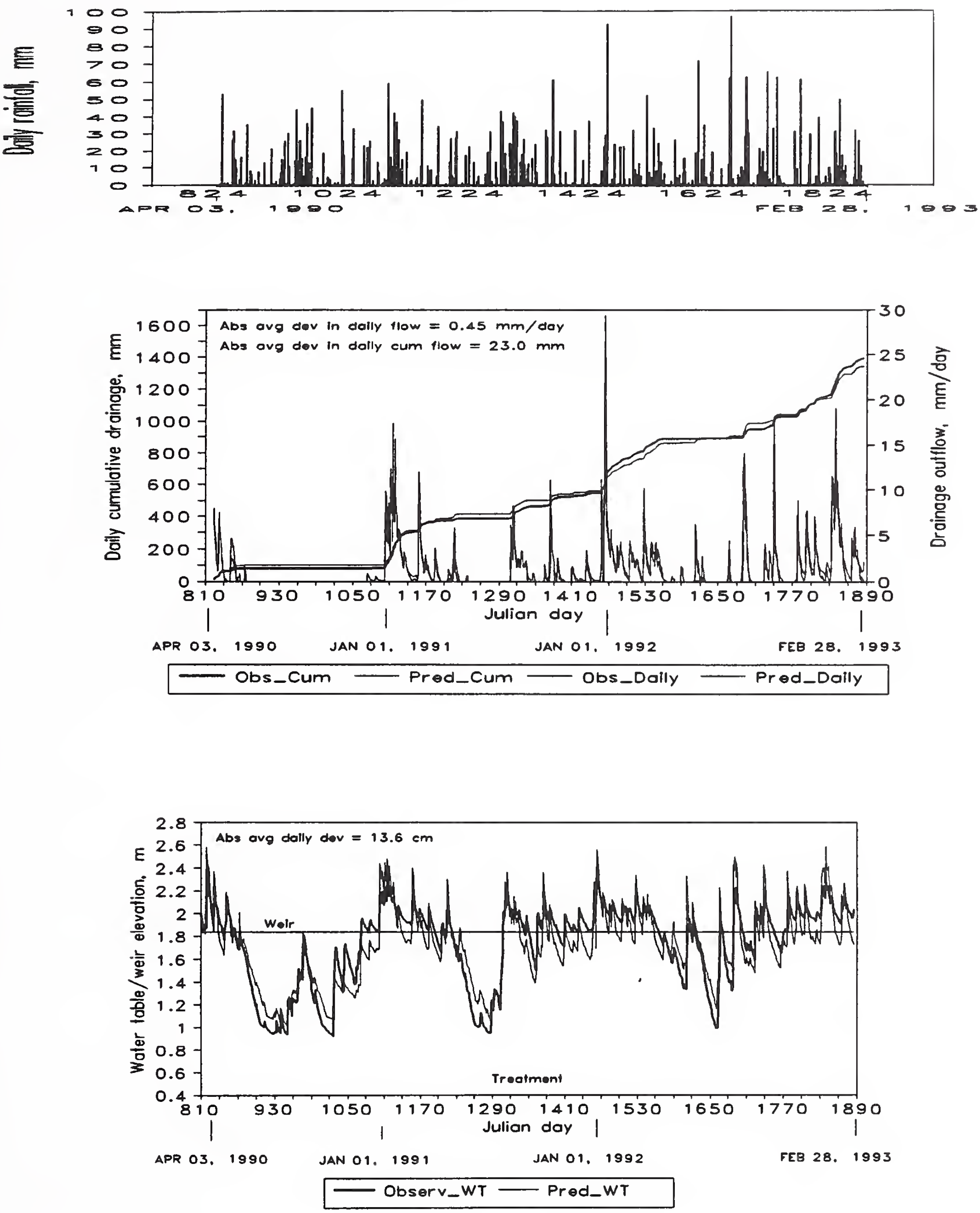


Figure 5. Rainfall (top), predicted and observed daily and daily cumulative drainage volumes (middle) and water table elevations with weir levels (bottom) for watershed 1 for treatment period (April 03, 1990 - February 28, 1993).

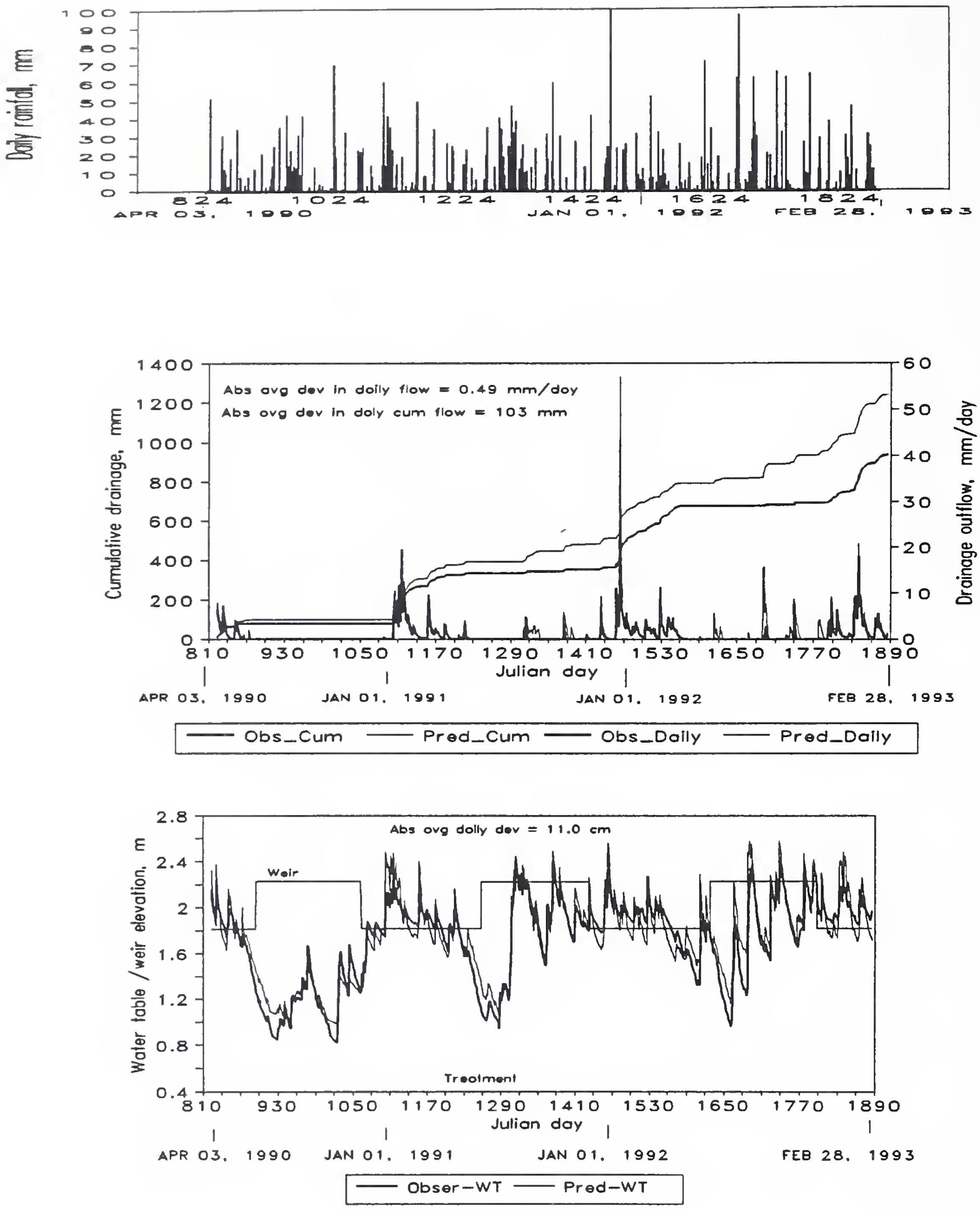


Figure 6. Rainfall (top), predicted and observed daily and daily cumulative drainage volumes (middle) and water table elevations with weir levels (bottom) for watershed 2 for treatment period (April 03, 1990 - February 28, 1993).

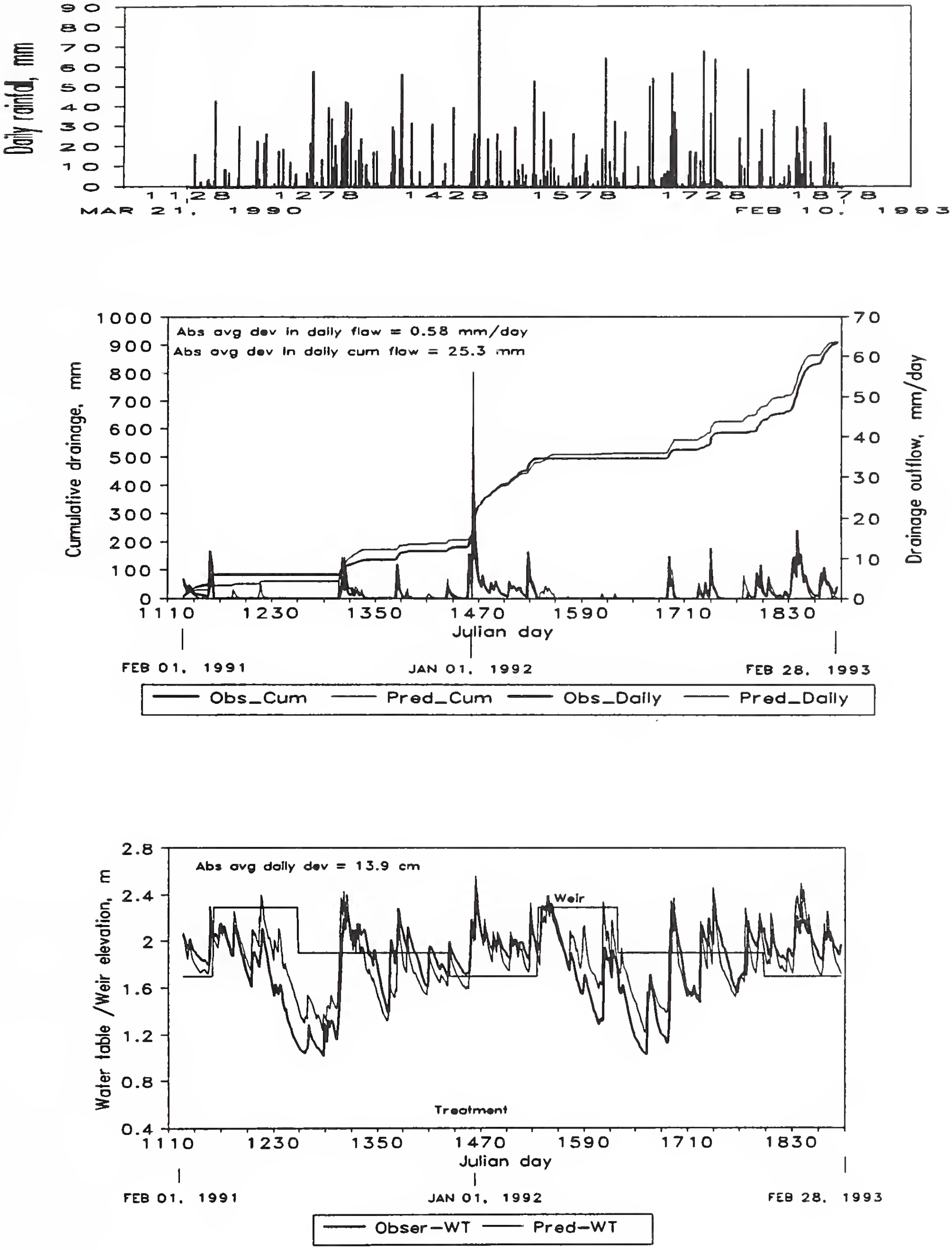
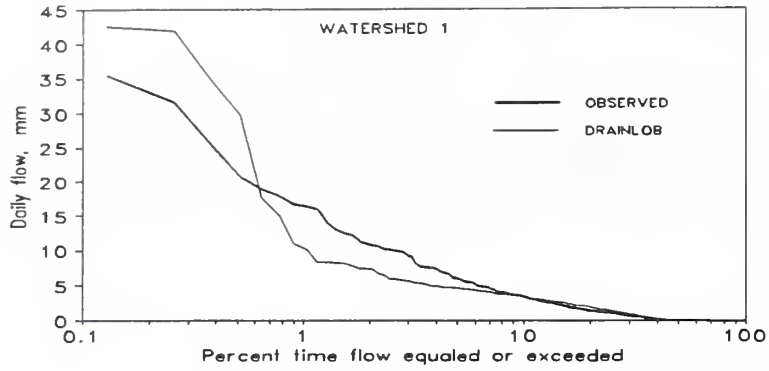
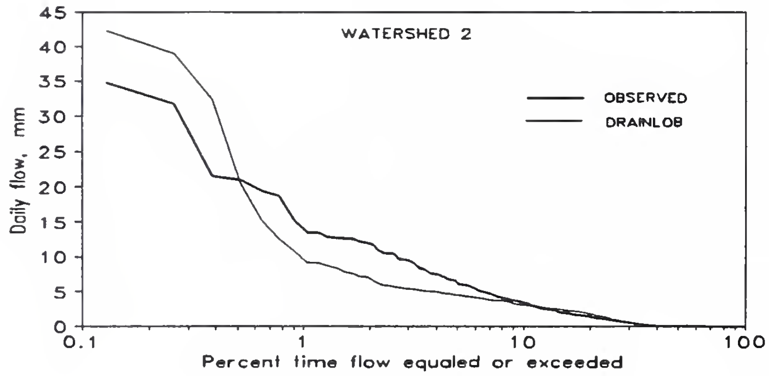


Figure 7. Rainfall (top), predicted and observed daily and daily cumulative drainage volumes (middle) and water table elevations with weir levels (bottom) for watershed 3 for treatment period (February 01, 1991 - February 28, 1993).





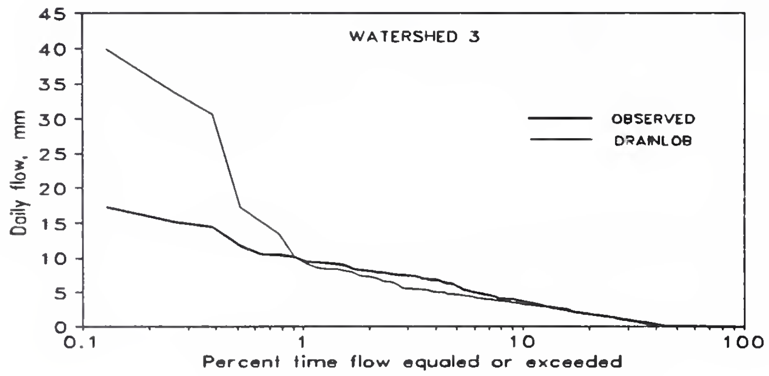


Figure 8. Comparison of observed and predicted daily flow duration curves for three watersheds for calibration period (February 02, 1988 - March 19, 1990).

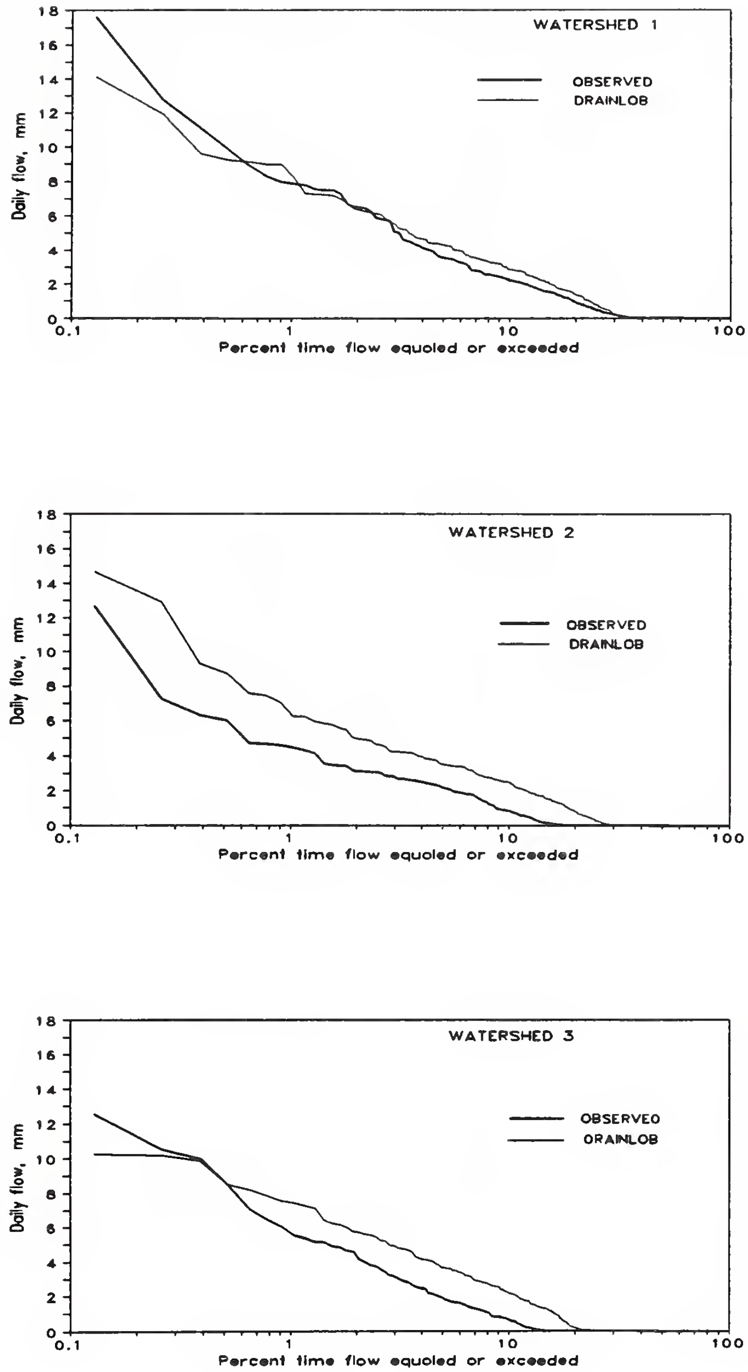
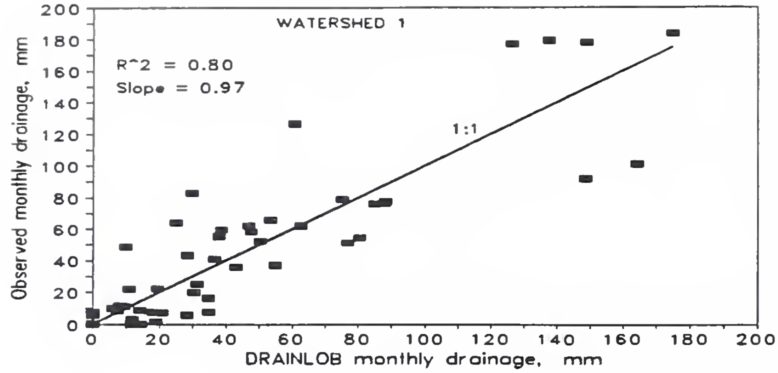
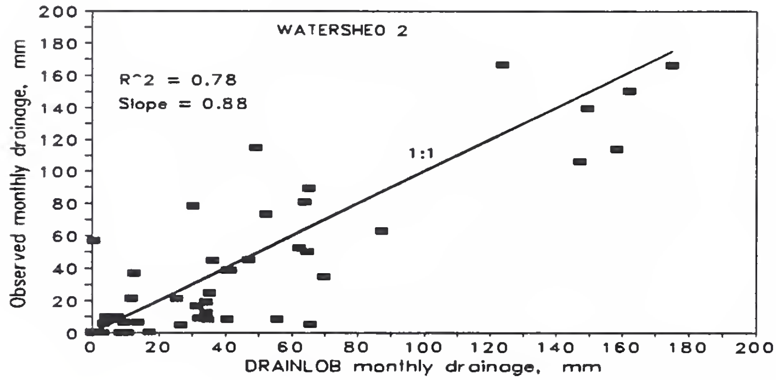


Figure 9. Comparison of observed and predicted daily flow duration curves for three watersheds for a three-year treatment period (April 03, 1990 - December 1, 1992).





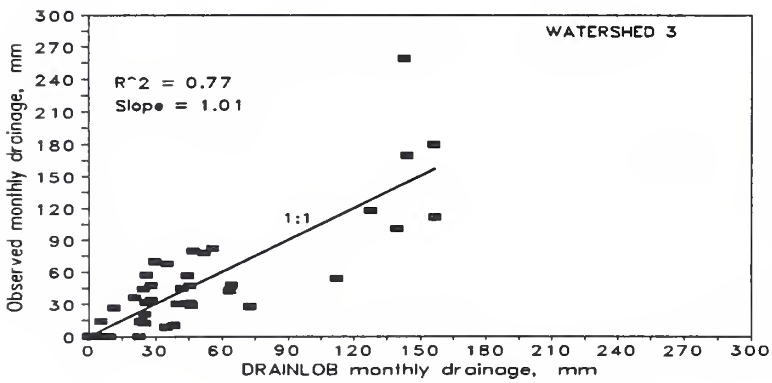


Figure 10. Comparison of observed and predicted monthly total drainage volumes for three watersheds for a five-year period (1988-1992).

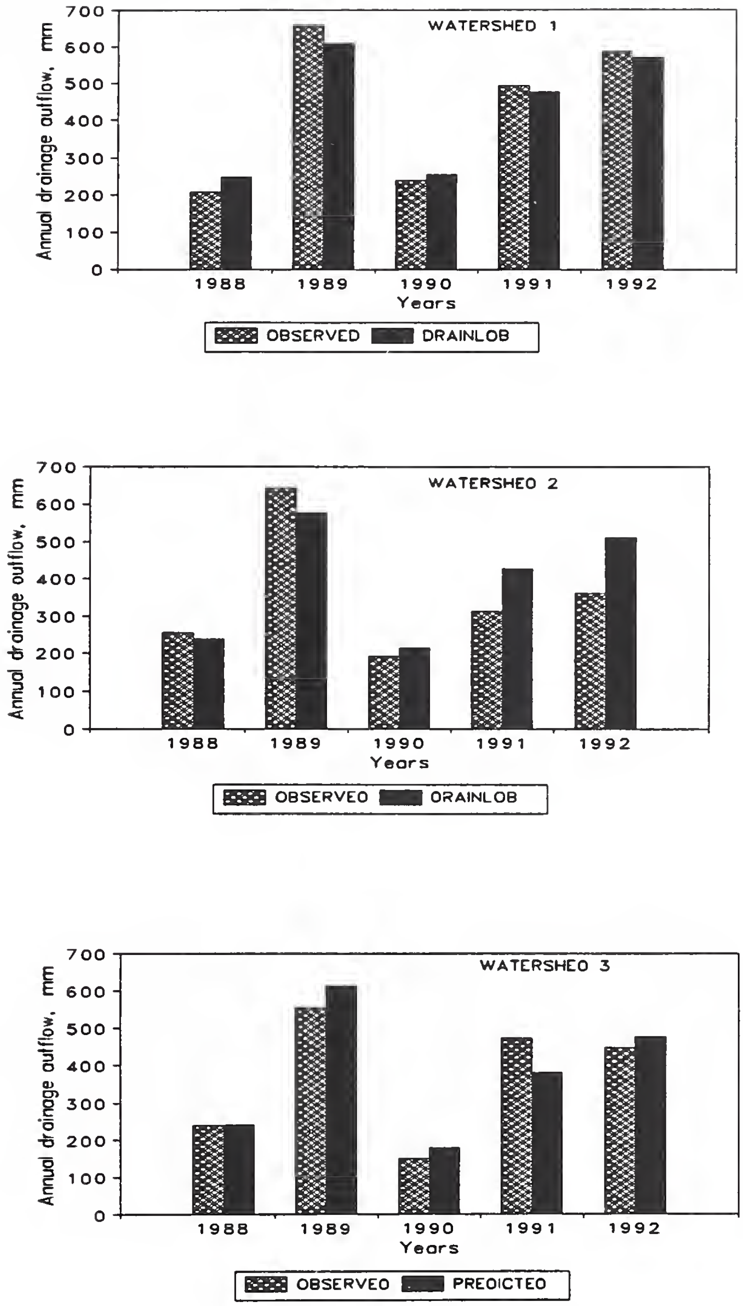


Figure 11. Comparison of observed and predicted annual drainage volumes for three watersheds for a five-year period (1988-1992).

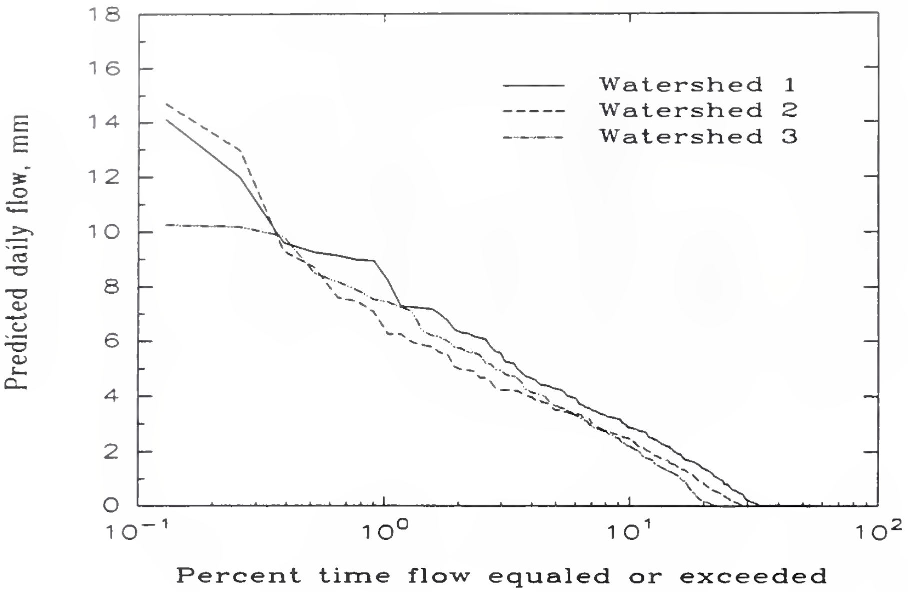


Figure 12. Flow duration curves of daily flows predicted by DRAINLOB for three watersheds for the treatment period (April 03, 1990 - December 01, 1992).

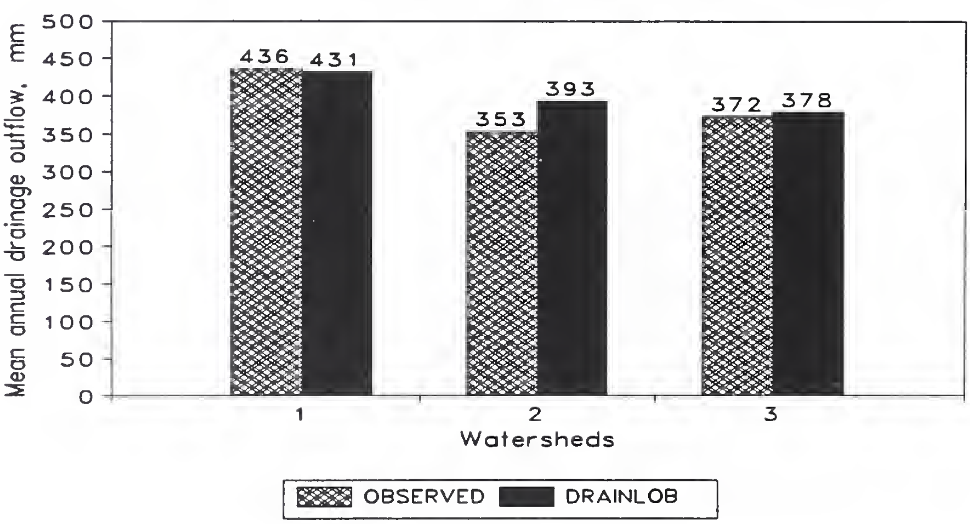


Figure 13. Comparison of observed and predicted mean annual drainage outflows averaged over a five-year (1988-92) period for three watersheds.

NOTES

HYDROLOGIC RESPONSE OF NORTHERN WETLANDS TO SILVICULTURAL WATER MANAGEMENT SYSTEMS

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Abstract. -- Two types of water management systems are used to ameliorate saturated soil conditions which limit silvicultural operations and site productivity in northern wetlands. The pattern ditch system is an intensive drainage network designed to regulate water table depth in peat soils. The prescription drainage system is a low-intensity drainage system that is used to develop apparent drainage patterns in mineral and histic-mineral soils. These water management systems may either increase or decrease peak flow, base flow, and the duration of peak flow events, depending on drainage system design, climate, season, site characteristics, and land use. The most common hydrologic response to drainage is an increase in peak flow and base flow, and an increase in annual runoff. The effect of wetland drainage on watershed hydrology depends on the proportion of the watershed drained. Drainage may also affect water quality, nutrient cycling, vegetation composition and structure.

INTRODUCTION

Saturated soils in northern forested wetlands affect silviculture by limiting site productivity, tree species suitability, regeneration potential, and operability. Water management systems involving the use of open, surface drainage ditches have been developed from the early 1900's to ameliorate those limitations caused by soil saturation. The application of those water management systems in northern wetlands has assisted the development of commercial forest resources. Approximately 9.3×10^6 ha of northern wetlands have had silvicultural water management systems installed with over 90 percent of that land occurring in Finland and the former USSR (Paivanen 1991; Vompersky 1991). In northern North American wetlands however, the application of water management practices have been quite limited compared to other countries. With no recent inventory data for lands affected by silvicultural water management systems in northern North America available, the current total area is estimated at less than 25,000 in Canada (Haavisto and Jeglum 1991), and less than 15,000 ha in the Great Lakes region (Minnesota, Wisconsin, and Michigan) of the U.S. (Trettin et al. 1991). Although early studies and subsequent work have shown enhanced tree growth with drainage (Payandeh, 1972; Rothwell et al. 1993; Trottier 1991; Zon and Averell 1929), the costs, uncertainties associated with drainage responses, and alternative wood resources have precluded large-scale application of silvicultural drainage. Now, particularly in Canada, there is a renewed interest in the use of silvicultural water management (Haavisto and Jeglum 1991; Hillman 1987).

The purpose of silvicultural water management systems is to control surface water conditions in order to enhance site productivity potential and improve operability conditions. Consequences of water table manipulation include changes to base flow, storm flow, and storm flow duration. Those effects may be manifest in the individual wetland and the encompassing watershed. Other ecosystem processes are also affected including site productivity (Hanell 1988; Penttila 1991) and species composition (Kurimo and Uski 1988; Lieffers and Rothwell 1987), organic matter decomposition (Trettin et al. 1994), soil fertility (Braekke 1987), and water quality (Lundin 1988; Sallantaus 1988). Changes in hydrologic regime and

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associated effects on the wetland carbon budget are particularly important since northern forested wetlands play a disproportionately important role in the global carbon budget (Armentano and Menges, 1986; Maltby and Immirzi, 1993).

The objectives of this paper are (1) to describe the types of drainage systems used for silvicultural water management in northern wetlands, and (2) to review the hydrologic response associated with the different drainage systems. Important hydrologic and edaphic properties of northern wetlands are also summarized to provide background for considering the hydrological response to drainage. Although a thorough review of other environmental impacts of drainage are not included in this paper, perspectives on the interrelationships between hydrologic responses to drainage and other ecosystem processes and the need for further research are discussed.

FACTORS AFFECTING SILVICULTURAL DRAINAGE SYSTEMS: HYDROLOGY AND SOILS

The hydrologic regime and soil type are the primary factors that affect the design of silvicultural drainage systems and the hydrologic response. Ground water, surface runoff, and precipitation are the sources of water which sustain the hydrologic conditions necessary for the development of northern wetlands (Boelter and Verry 1977; Carter 1986; Siegel 1988). Most northern wetlands are sustained by ground water discharge (Verry 1988); depending on the degree of soil organic matter accumulation and type of vegetation, these wetlands are commonly termed fens or swamps (Moore and Bellamy 1974). Fens are peatlands that vary from being treeless to treed without canopy closure. Swamps are forested wetlands that may have either thin or thick accumulations of soil organic matter. The constant ground water discharge through a fen or swamp produces a relatively uniform discharge pattern (Fig. 1). The chemistry of waters draining from fens or swamps is typically minerotrophic reflecting the influence of shallow and deep aquifers (Boelter and Verry 1977). In contrast, bogs are organic soil (i.e., peat) wetlands that are sustained primarily by precipitation (Moore and Bellamy 1974). Bogs form as a result of organic matter accumulating above the level of normal ground water influence with subsequent hydrologic isolation of the surface by low permeability organic soils layers. As a result, water from precipitation is 'perched' creating a ground water mound (Ingram 1992). However, bogs may not be completely isolated from ground water, and mixing of ground water with acidic bog water may affect water chemistry and hence structure and composition of vegetation communities (Siegel and Glaser 1987). The drainage from bogs exhibits a distinct seasonal pattern, with peak flows occurring in the spring, following snowmelt and moderate to low flows during the summer, fall, and winter (Fig. 1). It is not unusual for discharge from bogs to cease during dry summers or winters. For further discussions on the development and hydrology of northern wetlands see Damman (1986), Foster and Jacobson (1990), Glaser (1987), Glaser et al. (1990), Gore (1983), Ingram (1992), Moore and Bellamy (1974), Sjors (1990), Verry (1988), among others.

Accumulated organic matter is the most important soil property affecting hydrology and hydrologic functions of the wetland. Soil organic matter affects hydraulic conductivity, infiltration capacity, water holding capacity, and bulk density. Differences in those physical soil properties result from vegetation type and degree of decomposition (Boelter and Verry 1977; Gafni and Brooks 1990). Organic matter accumulates in wetlands as a result of vegetation production exceeding the rate of decay (Clymo 1984). The accumulated organic matter, whether composed of bryophytes, herbaceous, or woody vegetation, is termed peat. Soils with thin (<40 cm) peat layers are termed histic-mineral soils, and they represent nascent histosols. Histosols, or peat soils, are characterized by thick (>40 cm) accumulation peat that typically has two distinct zones. The upper zone (i.e., acrotelm) is characterized by a fluctuating water

table moderately decomposed peat and relatively high biological activity (Moore and Bellamy 1974). The lower zone (i.e., catotelm) is permanently saturated and usually consists of highly decomposed organic matter.

The hydrologic regime (bog vs. fen) and type of soil occurring in the wetland are important factors affecting the merit and effectiveness of silvicultural water management system. Poorly drained, nutrient poor bogs typically do not merit water management for silvicultural purposes unless intensive fertilization regimes are planned (Paavilainen and Paivanen 1988). In contrast, fens and swamps have inherently greater nutrient supply and typically higher productivity than bogs. The degree and type of organic matter accumulation on the soil surface also has a direct bearing on the type of drainage system that is applicable to the wetland.

TYPES OF FOREST DRAINAGE SYSTEMS USED IN NORTHERN WETLAND

The pattern and prescription ditch systems are used in northern wetlands. These two different types of water management systems result in quite different drainage patterns and water management regimes. The pattern ditch system is a highly engineered, dense network of ditches while the prescription ditch system tends to be more extensive, and is designed according to natural drainage patterns. The ditch density of these water management systems ranges from less than 15 m ha^{-1} for prescription drainage system to greater than 200 m ha^{-1} for pattern ditch systems (Trettin et al. 1991).

The pattern drainage system has been used most commonly in northern peatlands. It consists of a perimeter ditch that surrounds the drainage area (i.e., management area), one or more main drainage ditches, and lateral ditches that are typically arranged in a systematic or patterned manner (Fig. 2). Pattern drainage systems are used primarily on peat soils because the low hydraulic conductivity necessitates relatively close spacing of the ditches. Spacing between the lateral ditches may vary between 5 and 30 m. Ditching depth varies from 0.7 to 1.5 m in the main ditches and 0.4 to 0.7 m in the lateral ditches. Specifications for the ditching depth and spacing depend on hydrologic properties of the peat, precipitation, hydrology, and the desired drainage norm or effective water table depth at the mid-point between ditches. Drainage norms have been developed which specify ditch depth and spacing that are necessary to achieve a particular water table depth given the particular site and climatic properties (Braekke 1983; Paivanen and Wells 1978). Detailed descriptions of the design and configuration of pattern drainage systems are provided by Braekke (1983), Haavisto and Paivanen (1987), Paivanen and Wells (1978), Rosen (1986), and Trottier (1989).

The second type of water management system used in northern wetlands is the prescription ditch system. Ditch placement in this system is intended to augment the natural drainage of the site by developing the apparent drainage patterns (Fig. 3; Terry and Hughes 1978). The result is a low-intensity drainage network that can be functionally integrated into the watershed. Prescription drainage systems are particularly well suited to removing snowmelt in young glaciated landscapes and to soils that have a relatively high permeability (i.e., mineral or histic-mineral soils). They typically consist of a single main ditch (1-2 m deep and 2-4 m wide) that is positioned in apparent drainages. Secondary ditches (0.5-1.5 m deep and 1-2 m wide are also used to affect smaller areas and to develop a dendritic drainage pattern. Prescription ditch systems are typically designed using topographic maps and aerial photo interpretation, and field reconnaissance to identify drainage patterns. Since prescription drainage systems consist of a single ditch, widely spaced through the wetland, the water table response depends on the hydrologic gradient, soil permeability, precipitation, and ground water.

Operational considerations for both types of forest drainage systems include ditch and sedimentation basin maintenance. Ditch cleaning is required periodically to maintain the effectiveness of the ditch, particularly in peat and sandy soils where slumping and vegetation may reduce water movement through the ditch (Paivanen and Ahti 1988). Similarly, periodic monitoring and clean-out are required to maintain sediment removal capacity of the sedimentation basins.

HYDROLOGY OF WETLANDS MANAGED WITH PATTERN DITCH SYSTEMS

Water table response

Water table depth on peatlands managed with pattern drainage systems is controlled primarily by ditch spacing and depth (Fig. 4). Typically, the drainage system is designed to lower the average water table depth 30 to 40 cm (Paivanen 1991). However, water table fluctuations can range from near the soil surface to below the ditching depth (Berry and Jeglum 1988).

In fens, the area affected by pattern drainage systems is primarily limited to the area within the perimeter ditch and a marginal zone around the perimeter ditch. Since ground water discharge maintains the hydraulic loading in fens, the drainage effect is limited by hydraulic conductivity of the peat. For example, in some highly decomposed peats the affect of ditches is negligible within 5 m of the ditch (Boelter 1970). In contrast, ditching in bogs may affect the entire wetland because of the sensitive hydrological balance of the ground water mound (Ingram 1992).

Water yield and flow characteristics

The hydrologic response of peatlands to pattern drainage systems may be categorized into three models using peak flow, base flow, and duration of peak flow as response parameters (Table 1). The first model, Model A, is representative of drainage systems where peak flow increases while base flow and peak duration are reduced. The drainage ditches accelerate the removal of surface and subsurface waters resulting in 'flashy' hydrographs. Model B characterizes a drainage response of increased base flow and reduced peak flow. This response reflects moderation of peak flow as a result of increased soil storage. Water discharge from a wetland exhibiting a Model B response tends to be more uniform because of increased soil storage and base flow. In contrast, other pattern drainage systems may increase peak flow, base flow, and duration of peak flow (i.e., Model C). This response is particularly common following installation of the drainage system; however it maybe moderated following afforestation (Robinson 1986).

The effect of pattern drainage systems on peak runoff events depends on the drainage intensity, precipitation, vegetative conditions, and season. Following drainage, soil water storage capacity may be increased as a result of the lowering of the water table (Heikurainen 1980). Concomitantly, infiltration capacity and hydraulic conductivity may be reduced as a result of increased decomposition of the peat (Boelter and Verry 1977; McDonald 1973), and hence soil storage may actually decrease in the long term. During 'light' precipitation events, water retention in the unsaturated peat zone would result in reduced peak flow (e.g., Model B). In contrast, peak flows from undrained peatlands, for a comparable rainfall intensity, would tend to be greater because of a higher water table and hence reduced soil water storage capacity (Heikurainen 1980). During 'heavy' rainfall events surface and subsurface runoff and direct precipitation into the ditches increase which results in increased peak flow (e.g., Models A or C). Seasonal variations in water table depth and precipitation also interact with these drainage responses; runoff during 'dry' seasons tends to be dominated by base flow, while runoff during 'wet' seasons tends to

be dominated by peak flow (Starr and Paivanen 1986). Interception is another factor affecting the runoff response (Mahendrappa 1982). Increased forest productivity following drainage is manifest, in part, by greater canopy and leaf area development; that effect causes increased interception which contributes to reduced peak flow during light precipitation events (Heikurainen 1980). However, increased interception loss will not be evident until canopy closure which may be 10 to 20 years following initial drainage.

Increased base flow after drainage is a result of ditches lowering the outlet and shortening the flow path, and changing the amount of water lost through evapotranspiration. In undrained fens, ground water movement is slow as a result of the low hydraulic conductivity and long flow paths. As a result, the contributing area of the fen to discharge is relatively small and occurs in the immediate vicinity of the outlet (Brooks 1988). Drainage ditches shorten the flow path to a length that is approximately one-half of the distance between ditches. However, the area contributing to discharge increases with ditch density (Fig. 1). The perimeter ditch also increases the area contributing to discharge from the wetland (Brooks 1988). Reduced evapotranspiration also contributes to increased base flow (Brooks 1988; Starr and Paivanen 1986). In undrained wetlands, evapotranspiration is at the potential rate when the water table is within 30 cm of the surface (Verry 1988). When the water table is lowered below 30 cm from the soil surface, evapotranspiration will be lower than the potential rate thereby availing more water for subsurface drainage (Verry 1988).

In northern climates snowmelt is a major hydrologic event affecting water table depth and stream flow. The effects of pattern drainage systems on the peak flow during snow melt may vary depending on the position of the water table during the winter. According to Model A drainage would intensify the release of snow melt, similar to intense rainfall events. However, some observations suggest that snowmelt which releases large amounts of water when the water table is high maybe independent of the drainage system and behave different from rain discharge. For example for nine years following water management, Seuna (1980) measured increased maximum spring flow of 31 percent compared to a 131 percent increase during the summer. This response reflects a situation where the water table is elevated during the fall and winter, under both natural and drained conditions, and as a result the flow during snowmelt were similar. In peatlands where the water table does not rise significantly during the winter, the increased soil water storage capacity as a short-term result of water management, would dampen the discharge during snowmelt producing a Model B-type response (Heikurainen 1980).

Pattern drainage systems increase the total runoff from the wetland (Robinson, 1986; Starr and Paivanen, 1986). However, two factors may influence the amount of runoff following drainage: increased evapotranspiration and ditch impairment. Periodic (10-20 years) ditch maintenance is required to sustain the drainage efficiency (Paivanen and Ahti 1988). Otherwise blockages will eventually negate the effects of the drainage system. Evapotranspiration from a closed-canopy forest may effect a 'biological drainage' reducing the amount of discharge (Heikurainen 1980). Both Robinson (1986) and Seuna (1980) measured that response following afforestation of drained peatlands. However, forest harvesting would reverse that effect.

HYDROLOGY OF LANDS MANAGED WITH PRESCRIPTION DITCH SYSTEMS

Water table response

In contrast to pattern drainage systems which are designed to achieve a specified drainage norm, the water table response to prescription drainage systems is variable, depending on water inputs (ground water and

precipitation), soil hydraulic conductivity, and hydraulic gradients. Use of prescription drainage systems in northern Michigan in poorly drained histic-mineral soils have demonstrated that the change in water table depth is a function of distance from the ditch (Fig. 5). The greatest reduction in water table depth occurs within 50-100m from the ditch, but the ditch can influence the water table depth at 200 - 300 m from the ditch (Trettin et al. 1982, 1991). Prescription drainage systems are ineffective in peat soils because of the low hydraulic conductivity of the peat (Trettin, unpublished data).

Water flow characteristics

Prescription drainage systems change the routing of ground water flow through the wetland by shortening the flow path and reducing the retention time in the wetland (Fig. 6). Under undrained conditions, the ground water flow path would be expected to be perpendicular to the soil surface elevation. The prescription drainage system increases the hydraulic gradient thereby accelerating the flow of water from the wetland. Studies have not been conducted to measure changes in peak flow or base flow as a result of prescription drainage. However, it is likely that poorly drained, mineral soil or histic-mineral soil wetlands would exhibit either a Model B or C type response (Table 1). Soil water storage capacity is increased by lowering the water table, availing a larger soil volume to store precipitation and thereby dampen the storm peak flow (e.g., Model B). Alternatively, peak flows could be increased (e.g., Model C) because of the shorter flow path into the ditch. Total water yield from a prescription-drained wetland would also be expected to increase as a result of the reduction in evapotranspiration and shortened hydraulic routing, however there is no empirical data to confirm this response.

LARGE-SCALE EFFECTS OF SILVICULTURAL WATER MANAGEMENT SYSTEMS

Although water management systems induce changes in water table depth, total flow, and peak discharge characteristics in individual wetlands, whether those effects are evident at the watershed level depends on the proportion of drained lands to the total land in the catchment. Verry (1988) showed that maximum peak flow does not increase until 25 to 30 percent of the watershed is drained (Fig. 7). Similarly, Novitzki (1978) reported that flood flow did not increase until the proportion of wetlands and lakes in Wisconsin watersheds decreased below 30 percent of the land area. Modeling the effects of forest drainage on river discharge, Vompersky et al. (1992a) have demonstrated progressive increases in peak flow and total discharge as the proportion of drained forest land is increased. It must be noted however that the runoff response will depend on location of the managed lands within the watershed, proportion of the watershed gauged, storm paths, precipitation duration and intensity, and other land uses. Correspondingly, assessment of cumulative effects of forest water management practices on basin hydrology must consider other land uses, in addition to climatological factors and forest management practices within the watershed (Hyvarinen and Vehvilainen 1981).

CONCLUSIONS AND PERSPECTIVES

1) Pattern and prescription drainage systems are effective in ameliorating wetness limitations associated with commercially valuable tree species on poorly drained organic and mineral soils. Drainage reduces water table depth and typically increases annual flow and peak discharge from the wetland. The hydrologic effects of drainage are finite, with evidence of reduced affects after 10 to 15 years (Robinson 1986; Seuna, 1980).

2) The effect of forest water management systems on basin hydrology depends on the proportion of the

basin that is drained (Verry 1988). If less than 25 percent of the entire watershed is drained it is unlikely that changes in peak discharge would be measured. However, there is considerable uncertainty in characterizing the water budget of wetlands (Carter 1986; Winter 1981; Winter and Woo 1990) and associated cumulative effects of disturbance (Siegel 1988; Winter 1988). Important information needs include (a) understanding the hydrological linkages and processes between uplands, wetlands, and aquatic zones, (b) determining how the spatial arrangement of land types and uses within a basin affect river or stream hydrology, and (c) determining relevant temporal effects of drainage on hydrology.

3) Chemical characteristics of water draining undisturbed wetlands reflect hydrobiogeochemical processes along a flow path through uplands, wetlands and aquatic zones (Comeau and Bellamy 1986; Verry 1975; Verry and Timmons 1982). Altered wetland hydrology, as a result of water management, induces changes in organic matter decomposition, nutrient cycling, and vegetation composition and production. Water quality following drainage in forested wetlands reflects a composite response of those processes to the altered hydrologic regime. As a result, water quality may exhibit increased acidification or neutralization capacity, and increased or decreased levels of dissolved carbon and nutrients (Heathwaite 1991; Sallantaus 1988, 1992). Further studies are needed to ascertain the interactions between the altered hydrologic regime and water quality, and to determine how water quality is affected by drainage in different wetland types (i.e., bogs, fens, swamps).

4) Carbon-accumulating wetland soils (peat and histic-mineral soils) in northern wetlands comprise approximately 3 percent of the terrestrial soils, but those soils contain approximately 24 percent of the total global carbon pool (Maltby and Immirzi 1993). Since most forest water management systems are prescribed to carbon-accumulating soils, changes in the rate of organic matter decomposition and vegetation productivity, as a result of drainage, have important ramifications to global soil carbon pools and fluxes (Trettin et al. 1994). Increased temperature and improved aeration following drainage increase the rate of organic matter decomposition resulting in a net reduction in soil C. Improved data on partitioning carbon loss among gas emissions and leaching is needed to evaluate atmospheric and aquatic impacts associated with carbon loss from drained wetlands. Several recent studies have suggested that the loss of soil carbon may be mitigated by increased carbon sequestration in biomass (Laine et al. 1992; Vompersky et al. 1992b). How change in carbon allocation within the wetland affects wetland functions needs to be determined.

5) The focus of biological responses to water management has traditionally been on commercial trees. Much less attention has been given to issues of species diversity, community composition and structure (e.g., both flora and fauna) and successional dynamics. Research is needed to ascertain functional responses of the managed wetland particularly in context of its landscape setting. On-site responses which should be investigated include community composition and dynamics, nutrient cycling, and fauna. Studies of off-site affects particularly on stream biota and the role of the managed wetland in the landscape. Further information on these parameters are needed to develop a comprehensive assessment of water management effects on wetland functions.

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Table 1. Three models which characterize the relative change in peak flow, base flow, and duration of peak flow in peatlands drained using a pattern drainage system (after Starr and Paivanen 1986).

Model	Peak Flow	Base Flow	Duration of Peak Flow	References
A	+	-	-	Ahti 1980.
B	-	+	+	Heikurainen 1980; Lundin 1992.
C	+	+	+	Robinson 1986; Seuna 1980; Vompersky et al. 1992a.

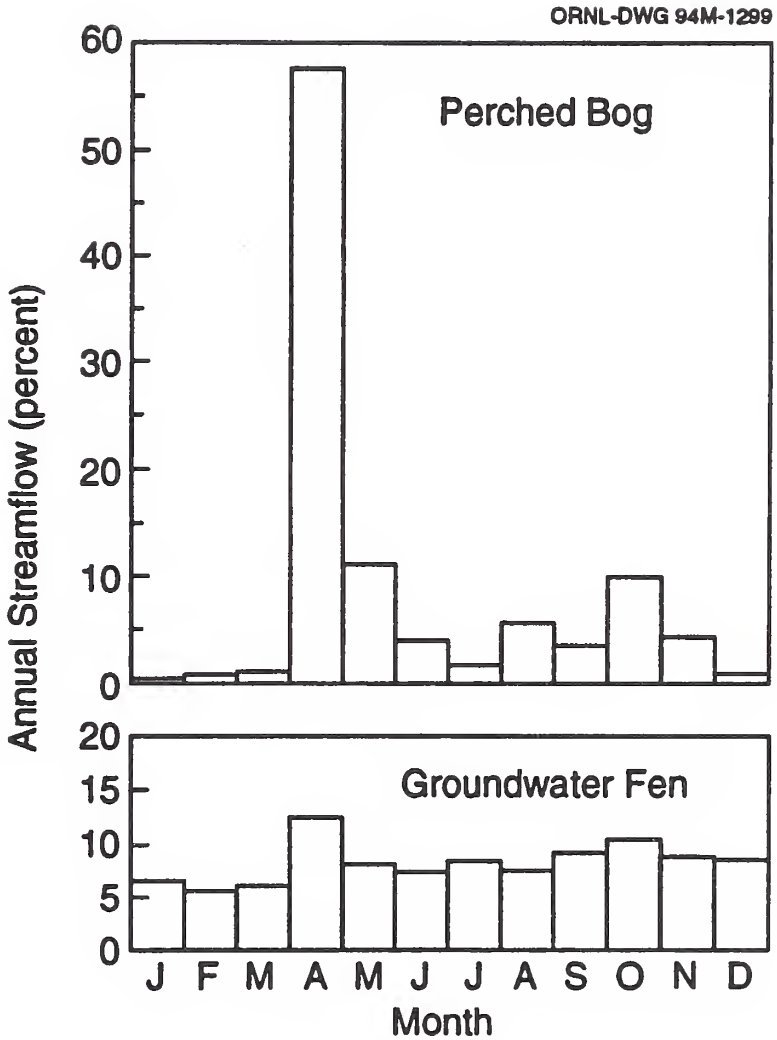

Figure 1 -- Monthly distribution of annual stream flow from a bog and fen in northern Minnesota (from Boelter and Verry 1977).

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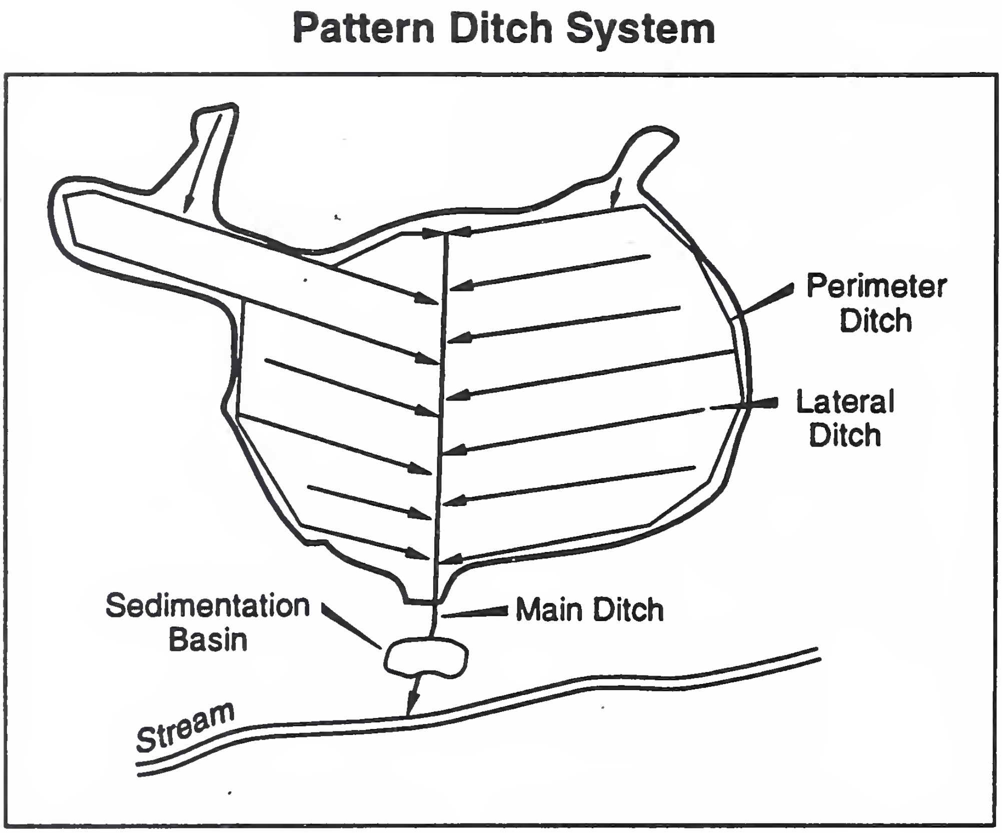

Figure 2 -- Schematic of a pattern drainage system.

ORNL-DWG 94M-1308

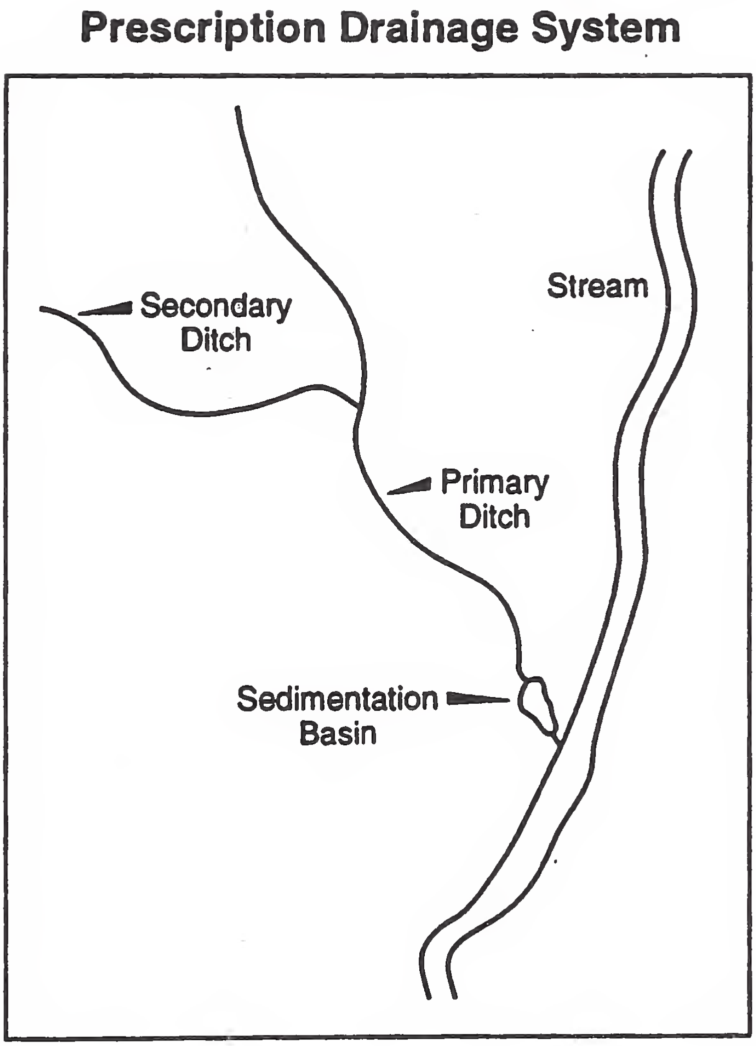

Figure 3 -- Schematic of prescription drainage system.

ORNL-DWG 94M-1348

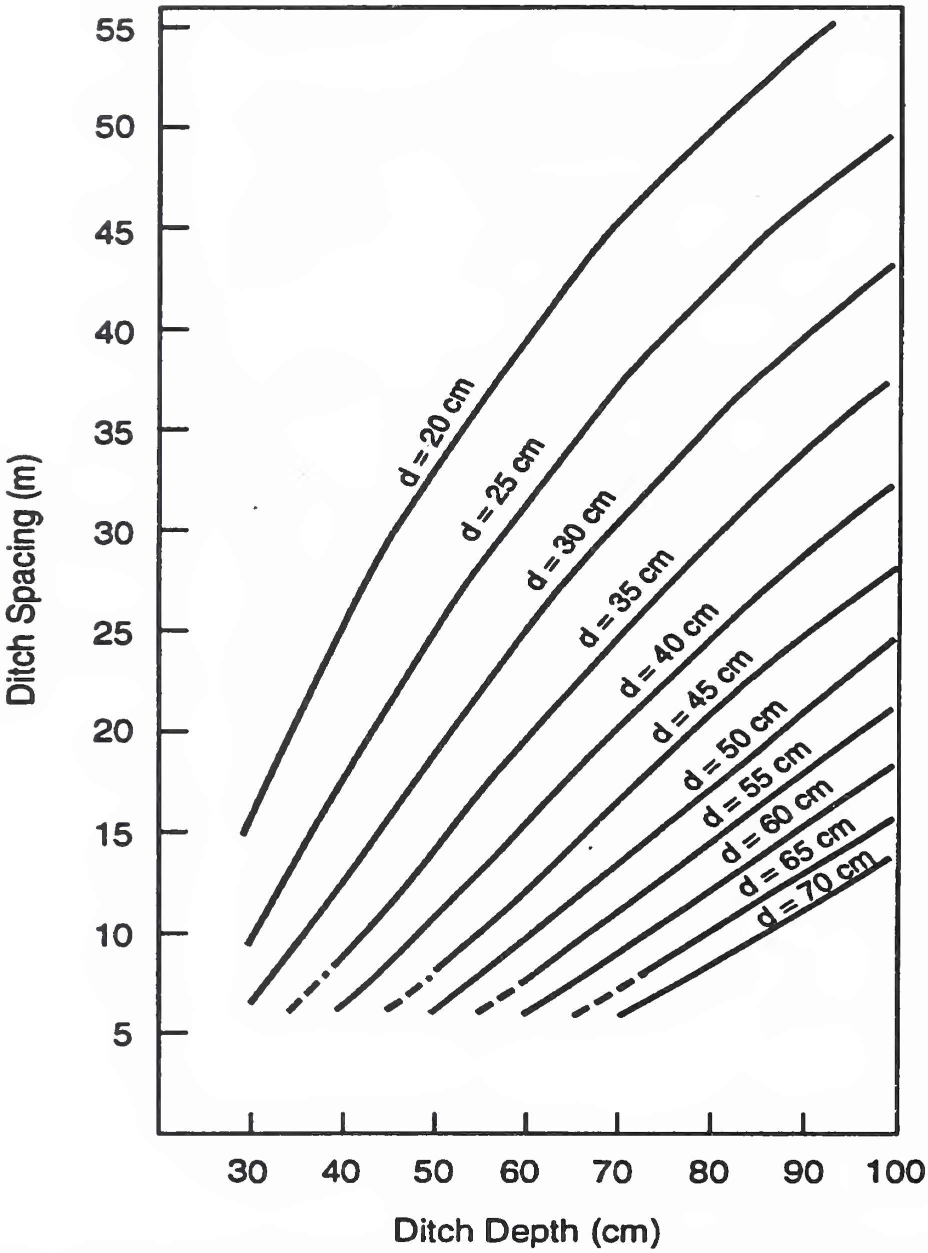

Figure 4 -- Drainage norm (d) achieved with different combinations of ditch spacing and depth (from Paivanen and Wells 1978).

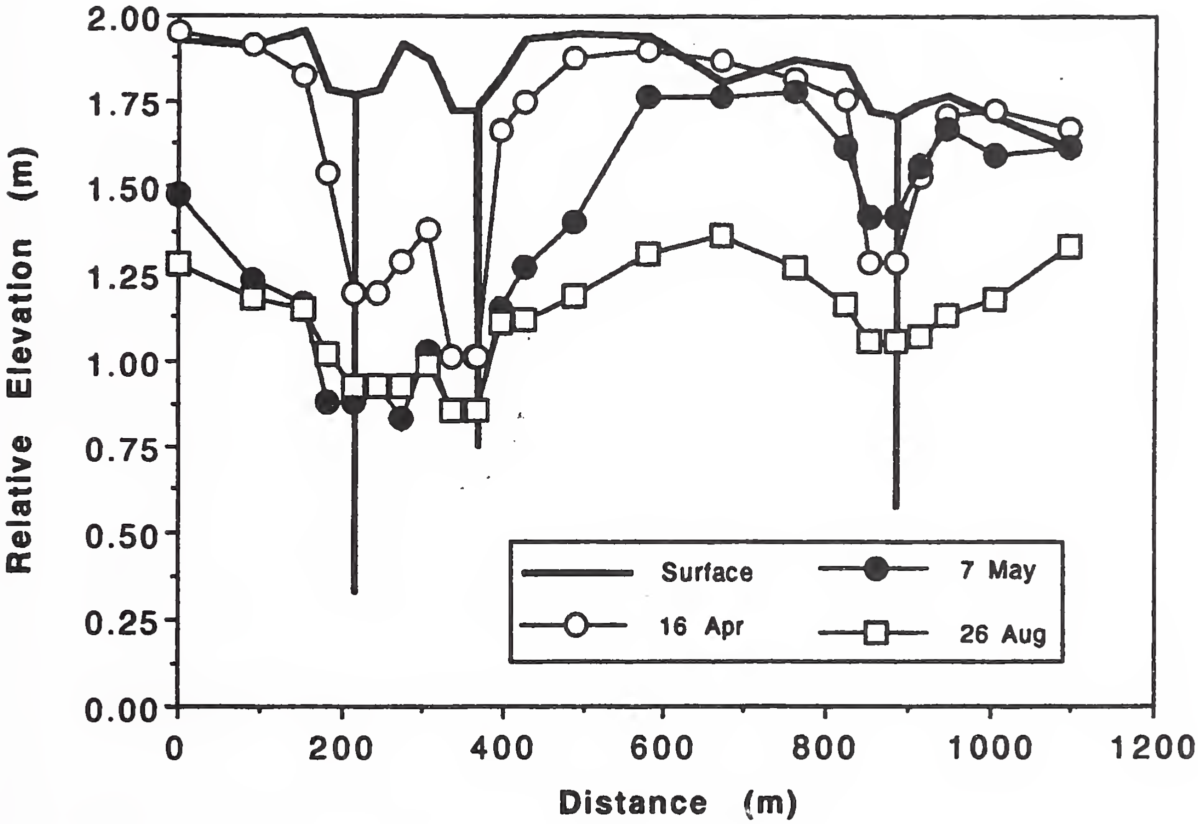

Figure 5 -- Water table depths perpendicular to a prescription- type ditch on a histic-mineral soil in northern Michigan (from Trettin et al. 1991).

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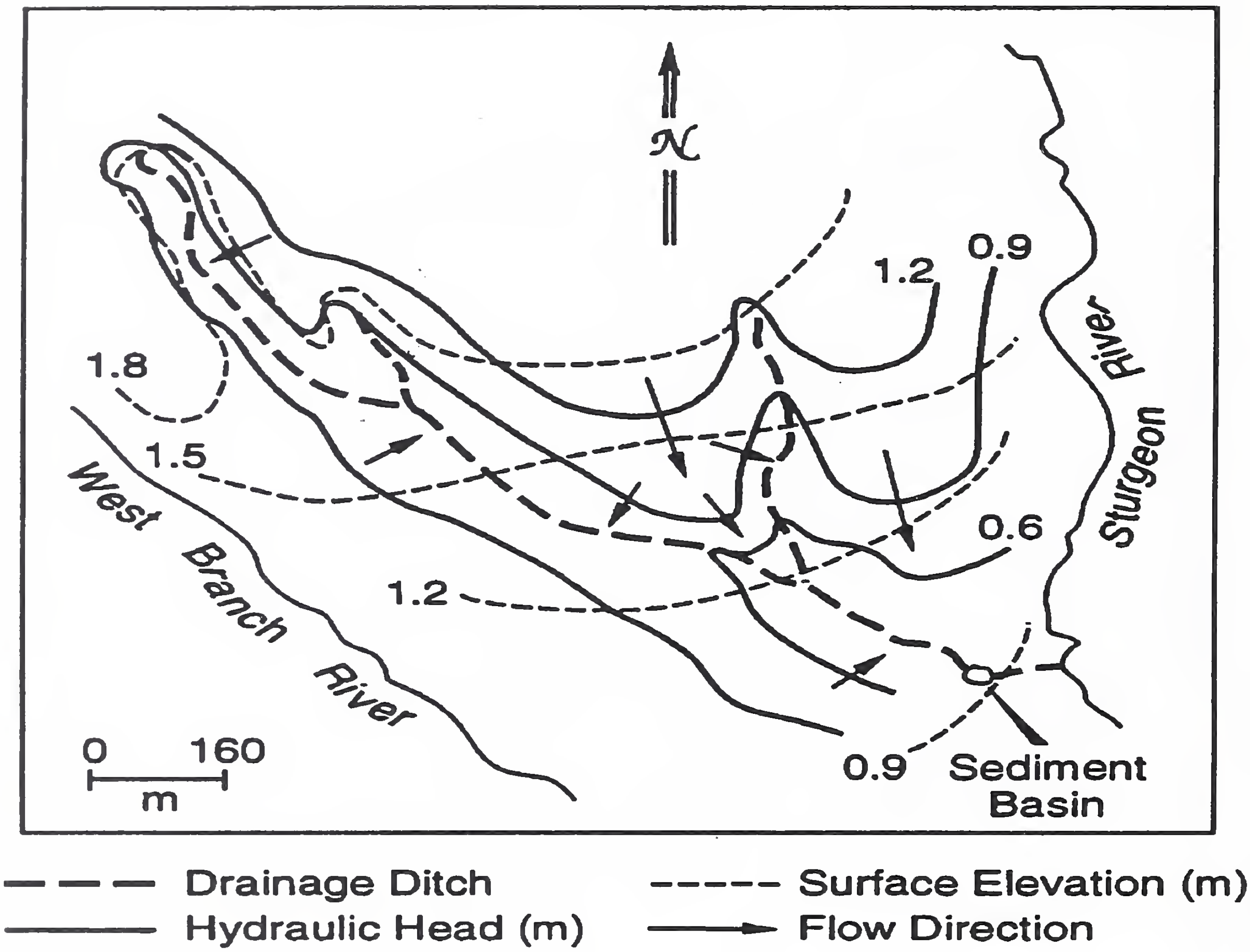

Figure 6 -- Hydrologic head isopleths in a histic-mineral soil wetland drained using a prescription-type drainage system. Topographic isopleths are shown in dashed lines. Arrows indicate direction of ground water flow. (from Trettin et al. 1991)

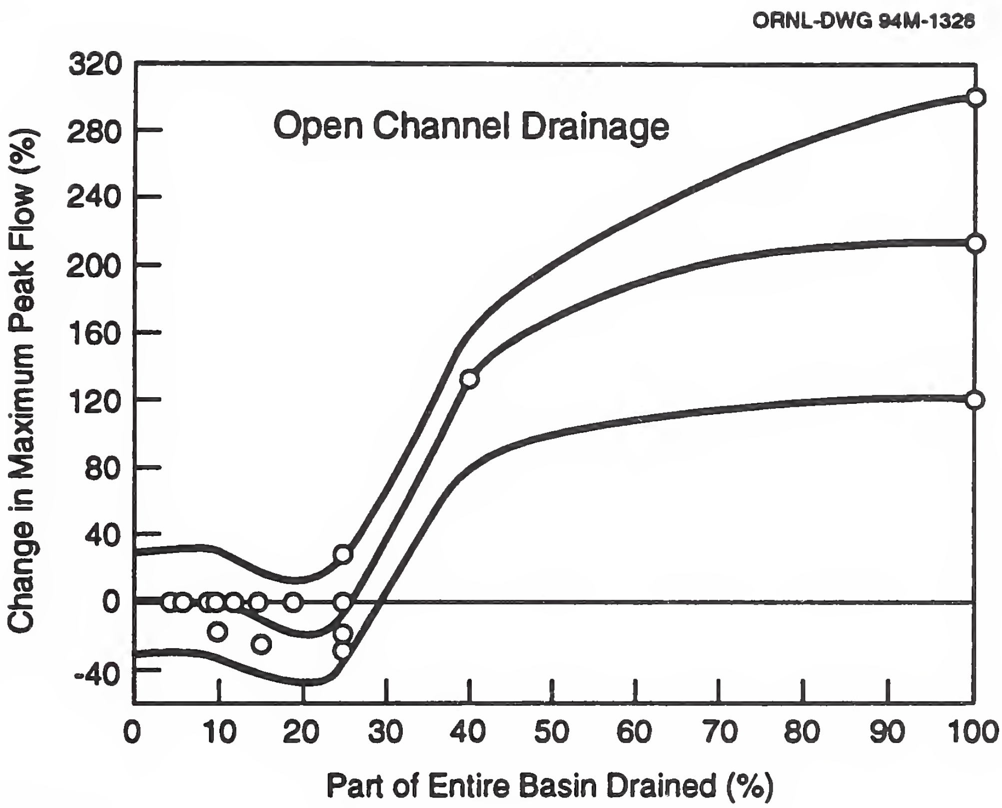

Figure 7 -- Change in maximum peak flow in relation to proportion of the basin drained with open ditches (from Verry 1988). The central line is bounded by theorized variation, open circles represent observations.

WATER QUALITY CHANGES ASSOCIATED WITH FOREST DRAINAGE.

Thomas M. Williams[1]

Abstract: Drainage of wet flats for pine plantation management results in little water quality degradation. Sediment is the most significant source of water quality degradation. Sediment is seldom as serious a problem in the flatwoods as in more hilly regions. The primary sources of sediment are ditch construction and roads. Alteration of road and ditch construction practices offers the greatest opportunity to minimize sediment concentrations.

Scope:

This paper will examine water quality effects associated with drainage for silviculture, primarily drainage for pine plantation management. Most of this type of drainage occurs on broad interstream divides where rainfall exceeds water loss by evapotranspiration, surface and subsurface drainage. These sites have several common names such as pocosin, wet flat, and pine flatwoods, each of which have slightly different meanings but all refer to generally the same hydrologic condition. The paper does not address, nor are the conclusions necessarily valid for, sites that are wet due to river flooding.

INTRODUCTION

Drainage of wetland forests for pine plantation management has been a matter of environmental concern since it began to be practiced in the early 1960's (Hewlett, 1972). By 1977, Klawitter (1978) reported that 2 million acres of wet sites had been drained for forest management purposes. Many of these 2 million acres were in large drainage projects conducted by forest industry on company lands. Terry and Hughes (1975) described the various techniques used by Weyerhauser in eastern North Carolina. With some exceptions, the techniques they describe were the industry standard until extension of jurisdiction of Section 404 of the Clean Water Act during the late 1970's. Since then the type of water management has changed from large systematic drainage installations to drainage of individual wet spots by, what is now termed, minor drainage.

Drainage for silviculture has three main goals. The most important goal is all weather access for harvest and site preparation. The second goal is to insure survival of planted pines, and the third is to increase the growth rate of planted pines. Meeting goals one and two are critical to success of a silvicultural operation. As we evaluate water quality from silvicultural applications it is important to keep in mind that Best Management Practices are those that minimize water quality degradation while still meeting the goals of the silvicultural operation.

A difficulty of appraising water quality impacts of forest drainage is that the research has been done primarily on operations with more extensive drainage than present silvicultural operations. Older research was done on sites that were drained by large ditches (Terry and Hughes 1975, Fisher 1981, Hollis et al. 1978). Later work has focused on harvesting of very wet sites (Aust et al. 1993, Aust et al. 1991). The change in focus is due to formulation of new Best Management Practices for Forested Wetlands which has created interest on very wet sites. Also most of the southern forest industries are no longer extending their base of pine plantation management. Much of the interest of industry is now on increasing yield of second generation pine plantations. Extending pine growing land by drainage is not practiced as widely as in the 70's and early 80's.

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Therefore, this paper will be an effort to extract conclusions from older data that relate to processes that may be applicable to minor drainage as it is practiced today. Much of the insight for this paper came from studies of drainage in coastal South Carolina in the early 1980's. That work was done on a chronosequence of subwatersheds created by the conversion of Kilsock Bay from pine hardwoods to pine plantation beginning in the mid 1960's (Askew and Williams 1984, Askew and Williams 1986, Williams and Askew 1988). Although chronosequence research does not provide conclusive proof, these studies did provide insight into the entire sequence of pine plantation establishment.

REVIEW

Sediment

Sediment is the most serious water quality problem associated with silviculture in southern forests (Ursic 1975, Yoho 1980). On the Kilsock Bay site we found that ditch construction and adjacent roads resulted in more suspended sediment than any other phase of pine plantation establishment (80mg/l vs 16 mg/l). Sources of sediment were material that slumped into the ditch from the bank and adjacent spoil, and material washed from the road surface. Sediment concentrations decreased after vegetation became established along the road margin and ditch bank during the second year. Sediment concentrations were also larger (20-30 mg/l) on subwatersheds where there were several road crossings. Riekerk (1983) found increased sediment (11-14 mg/l) from very intense site preparation that included windrowing, disking and bedding which lasted two years after treatment. Likewise, Hollis et al. (1978) and Fisher (1981) found logging and site preparation produced concentrations of 137 mg/l the first year and 28 mg/l the second year after treatment.

Forest management activities on pine flatwoods sites can increase suspended sediment concentrations from 3 to 20 fold over undisturbed controls. However, the main cause of the large percentage increases is the extremely small concentrations from undisturbed pine flatwoods. For example, the 14 mg/l concentration found by Riekerk (1983) was 3 fold over the control but is no higher than Neary and Currier (1982) reported for an undisturbed watershed in the Blue Ridge Mountains. Likewise, the value reported for drum chop site preparation (Riekerk 1983, Askew and Williams 1984) are below the 10 mg/l found by Rogerson (1971) for undisturbed watersheds in the Quachita Mountains in Arkansas. With the exception of raking debris into windrows, most forest management activities produce little sediment and result in runoff water quality that is highly satisfactory. Installation of drainage ditches and road design are the two areas where potential gains in water quality might be achieved.

Nutrients

Regeneration of pine plantations on poorly drained sites results in large changes in ecosystem processes which may release nutrients into runoff water. Natural variations of soil saturation (Lipscomb and Williams 1989), rapid rise of the water table after logging (Trousdell and Hoover 1955), and oxidation - reduction reactions of saturated soils (Redman and Patrick 1965) all contribute to unique chemistry of wetland forest ecosystems. A variety of changes were detected in the various subwatersheds of the Kilsock Bay study (Williams and Askew 1986) that were consistent with other nutrient cycling research.

Nitrogen (Nitrate)

While many upland forests are noted for conservation of nitrogen and small nitrate losses (Swank 1988) pine flatwoods show high nitrate concentrations at certain times. Riekerk and Korhnak (1985) reported

nitrate-nitrogen concentrations of .5 - 1.5 mg/l during dry years on control watersheds. Likewise, in fertilized experiments in North Carolina (Shepard in press) reported that NO_3-NO_2 values varied from 0- 1.2 mg/l on both before and after fertilization. The Kilsock Bay studies examined control subwatersheds, along with drained, logged, site prepared and young pine subwatersheds. During dry periods in 1981 and early 1982 (the same years that Riekerk observed high values) the control subwatershed NO_3-N concentrations were from 1 - 1.5 mgl/l (Williams and Askew 1986). On the subwatershed that was drained but had natural hardwood the values were over 3 mg/l. However, on subwatersheds that were logged, site prepared or had young pine values never exceeded 0.5 mg/l. The 15 year old pine plantation also had values near 1 mg/l. At Kilsock Bay and in Florida, high nitrate concentrations were associated with periods of low water tables. We (Williams and Askew 1986) found that concentrations were highest in the first stormflow after a dry period with low water table. Concentrations declined with succeeding flows and were always low during periods when the water table was near the surface.

All these findings are consistent with an oxidation-reduction control of nitrate production. High transpirational demand will lower the water table in forested wetland rapidly resulting in aeration of formerly saturated soil. This would allow microbial uptake of nitrogen and subsequent nitrification. With little rain nitrate might accumulate in the soil if uptake by roots was hampered by the change from anaerobic to aerobic conditions. The first large rain might be expected to leach any accumulated nitrate and produce higher nitrate concentrations in runoff. Succeeding storms would have a smaller reservoir of nitrate and might be expected to have lower nitrate concentrations. Also denitrification has been found the deplete nitrate in soils within 30 days of saturation (Patrick and Tusneem 1972).

Drainage, even that which removes only standing surface water, will result in more frequent drying of the soil and might contribute to increased nitrate concentrations. Logging and site preparation removes the vegetation which drives evapotranspiration and would make soil drying less frequent. Phosphorus fertilization allows rapid pine growth on poorly drained soils (McKee and Wilhite 1986) and might be responsible for uptake of nitrate on young pine sites even if the water table does fluctuate.

Many of the aspects of pine plantation management eliminate pulses of nitrate concentrations that have been found on several studies of undisturbed pine flatwoods or mixed pine-hardwood flats. Pulses of high nitrate concentrations from anthropogenic sources have been considered degradation of water quality. Can removal of these natural pulses be considered water quality improvement?

Sulfate

Sulfate has not been measured in most studies of pine management impact on water quality. We did measure it at Kilsock Bay since the soil there is a former salt marsh plain on a young marine terrace (Colquhoun 1974). Sulfate concentrations showed similar trends to nitrate which tends to strengthen our belief that nitrate concentrations were controlled by oxidation-reduction reactions. Sulfate was also the dominant anion in runoff water and highly correlated to calcium and magnesium concentrations (r^2 = 0.7 and 0.8 respectively). The effect of drainage on sulfate concentrations was not consistent in paired subwatersheds. Sulfate has little water quality or site productivity significance. Its only role may be as a counter ion to magnesium and calcium on young marine terrace soils.

Cations

Calcium, magnesium, and potassium are the cations most often affected by pine plantation management. Although drainage, logging and site preparation often result in small statistically significant changes in

concentrations of these elements the changes are not significant to water quality. These elements are usually in sufficient supply in forest soils and slightly increased losses during regeneration are not important to site productivity. Since the divalent cations were highly correlated to sulfate at Kilsock Bay, logging and site preparation treatment also had decreased concentrations of magnesium and calcium. However, in Florida, calcium concentrations were higher on treated watersheds than on the control.

Potassium concentrations are consistent in wetland forest studies and are similar to upland forests (Neary et al. 1988). Increases in potassium concentrations in runoff are roughly proportional to the severity of ecosystem disturbance. In Florida, potassium concentration increased from 0.18 mg/l in the control, to 0.55 mg/l in the minimum site preparation treatment, and 0.90 mg/l in the maximum site preparation treatment (Riekerk 1983). In Kilsock Bay potassium concentrations were 0.61 mg/l for the control, 0.90 mg/l for the drained subwatershed, 1.19 mg/l for the drained and logged subwatershed, and 1.45 mg/l for the drained, logged and site prepared subwatershed. Interesting data were also collected at Kilsock Bay during tropical storm Dennis, when 16 cm of rain fell in a 6 hour period. Potassium concentrations increased over two fold for two days following the storm. Roughly 80% of the area was flooded during these two days and flood waters were in close contact with the forest floor. This single natural event probably leached more potassium from the site than any forest practice.

Hydrogen ion

Natural pine flatwoods and pine-hardwood stands produce runoff water that is quite acid with pH values between 3.5 and 5. Weak organic acids associated with slowly decomposing litter are the usual cause of these low pH values. Activities associated with plantation establishment tend to lower the hydrogen ion concentration. On the Kilsock Bay study pH changed from 4.3 for the control, 4.8 for the drained, 4.9 for the drained and logged, 5 for the drained, logged and site prepared, 5.6 for the young pine plantation, and 4.9 for the 15 year old pines. In Florida, pH varied from 3.79 on the control to 4.04 on the maximum intensity site preparation treatment. It seems that treatments that remove the thick litter layer result in a decrease in runoff pH. The disturbance of regeneration seems to increase pH and it declines slowly as litter accumulates under the new stand.

Dissolved Oxygen

Dissolved oxygen is a critical factor for aquatic organisms. However, oxygen relations in streams are complex interactions of physical and biological processes which vary with both time and space. In Kilsock Bay, we measured dissolved oxygen but found very few conclusive processes associated with forest management. There were some observations that may be useful for consideration of drainage. Generally physical aeration seemed to be the most important factor in determining oxygen concentration. Highest concentrations occurred during the rising limb of the hydrograph when rain drops disturbed the water surface, and where culverts added water from different depth ditches. Water draining from the entire 6000 acre site did have a significantly higher mean concentration than the control subwatershed (6.5 mg/l vs 5.1 mg/l).

SUMMARY

In general pine plantation management did not seriously degrade water quality. Runoff from undisturbed wet flat forests is low in sediment, low in most dissolved nutrients, occasionally high in nitrate nitrogen following dry periods, and high in dissolved organic acids with pH around 4. Installing drainage ditches results in 5 - 10 fold increases in suspended sediment which lasts for about two years before ditch banks stabilize. Removal of surface water may also increase the intensity and frequency of high nitrate concentrations. Logging and site preparation seldom have measurable effects except to return the site to high water table conditions. Very intensive site

preparation which includes raking residuals into windrows appears to have a slight impact. Potassium concentrations are very sensitive to forest floor disturbance. However, when the entire sequence of pine plantation management is compared to undisturbed forest, water has higher pH, lower nitrate, and possibly slightly higher dissolved oxygen.

RECOMMENDATIONS

These recommendations are offered under a philosophical assumption that forestry should attain the least impact possible on water quality. I think a case could be made that pine plantation forestry in the flatwoods already meets more stringent goals of water quality than any other regulated activity. Sediment is the largest problem and the worst sediment concentrations are 10 fold less than contributions in the hilly coastal plain (Beasley 1979, Blackburn et al. 1986) which are still well below what is considered acceptable in agriculture. A site preparation treatment that was considered the maximum possible mechanical disturbance had sediment concentrations comparable to an undisturbed Blue Ridge Mountain stream. However, I think further reductions are possible using a few simple design criteria.

These recommendations for pine drainage require careful consideration of the subtle natural gradients found throughout the coastal plain. In the 60's and 70's plantation management depended on the large dragline, backhoe, and bulldozer. Roads were straight with large ditches, backhoe ditches emerged at right angles, and bulldozers piled debris in windrows and bedded perpendicular to the ditch. Small natural drains were ignored and often were crossed by both windrows and beds. Drainage and forest management that recognizes the subtle natural topography of the coastal plain can be done with smaller equipment and less disturbance to the environment. The goal of these recommendations is to create a forested landscape with roads on the best drained areas and drainage ditches in the lowest topographic positions that extend the natural drainage of the site.

Drainage Ditches

The broad flats that have been drained for pine silviculture are wet because they are on young marine deposits that have not developed natural streams. As deposits age, drainage networks develop and channels migrate headwards to increase the length of streams per unit area (Leopold et al. 1964). Drainage can be accomplished by simulating this natural process. Isolated wetlands can be connected to existing streams by small ditches which follow the natural low points. The depth of these auxiliary ditches can be adjusted to maintain the wetland character of the isolated areas. By allowing natural stands to parallel the ditch, small riparian zones can be created and the ditch can begin to function as a natural stream. The isolated wetlands will shrink slightly and will fluctuate less. The topographic low points will be drained by the ditch creating a narrow more stable riparian zone. The result of such a system will be to change natural isolated wet sites into a riparian system with slightly more stable water tables and spatial extent. The remaining landscape will be slightly drier and represent a better risk for investments needed for intensive forest management.

Roads

The most important aspect of roads is that they be designed to accomplish their task. Nothing produces sediment better than a skidder dragging a loaded log truck down a muddy road. Also the logger looses money from broken equipment, the land owner loses access to his forest, and the forest products company loses a constant supply of raw material. Roads should follow natural topographic high points even if these high points are less than a foot above the surroundings. Roads should cross natural drains or ditches at right angles and at narrow spots. Road ditches are usually necessary both to keep the road dry and as a source of road bed material. However, where the

road crosses areas that are highest, the road ditch can be of minimal depth. In this way the road ditch conveys primarily road runoff rather than being a drainage structure. Also road sediments are not immediately added to drainage water.

The most critical portions of road construction are crossings of drains or natural streams. The road should remain dry and the road foundation should not be saturated. Again the goal is to keep the road functional and prevent sediment caused by traffic churning a muddy road. However, groundwater will flow parallel to the stream and an impermeable road bed will impound this flow. An effective solution is an interceptor ditch on the upstream side of the road, a distribution ditch on the downstream site, and adequate culverts through the road fill. The road bed should be sufficiently wide that the road surface and a vegetated buffer will fit between the interceptor and distribution ditches. The culverts should be long enough to extend well beyond the road bed and the culverts set deep enough to carry water from the interceptor ditch to the distribution ditch when the water table in the drain is at or slightly below the soil surface. At wetland crossings the road ditches should turn from the road and discharge across the soil surface into the stream margins at points away from the interceptor and distribution ditches.

Previous research supports these recommendations in the following ways. Pine plantation management activities will not affect water quality if the pine land is separated from the stream or ditch by a small riparian zone. If the ditches that carry the bulk of the water are not along roads, there will be less opportunity for road sediments to enter the water. If roads are on the highest topographic positions, road ditches will drain only the roads. Road ditch water can be delivered to the surface of riparian zones at "stream" crossings that should allow the filtration of road sediments.

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HISTORICAL PERSPECTIVE

J. Paul Lilly

ABSTRACT.--Southern forested wetlands are attractive as sources of wood products and as potentially productive agricultural land. They have been extensively modified by man's activities. Most oak and gum swamps have been converted to farmland. Railroad logging dominated in the late 1800s through the early 1900s. Repeated wildfires have caused dramatic shifts in pocosin vegetation. In the 1930s much cut over land was acquired by paper companies, coinciding with a move toward sustainable forestry. Loblolly pine was known to respond to drainage and roads were needed for access. Forestry drainage activity accelerated beginning in the 1930s and continuing until now.

INTRODUCTION

This is primarily a historical perspective of forested wetlands in North Carolina, but many of the principles and forces described here are relevant to other areas of the South. Parts of this presentation have been published as a history of swamp land development in North Carolina (Lilly 1981b).

Beginning with the first successful English settlement in Jamestown Virginia in 1607, forested wetlands have been the object of continuing exploitation and modification. The first European settlers did not find an entirely pristine wilderness on the east coast of America (Fernow 1911). Over many years the American Indians had modified their environment to meet their needs. Land near long-term village sites was in shifting cultivation. The land would be cropped until the fertility level was too low to sustain production, then it would be left idle while other land was used. Some of the earliest conflicts between Indians and settlers were over the settler's use of Indian "old fields" which were open and attractive to settlers but which the Indians considered theirs. Indian activity was limited mainly to the naturally better drained land.

The settlers saw the forest as a vast, limitless, forbidding resource and exploited it to the full extent of their abilities. We would be naive to think that the forests were not changed by this. Long leaf pine was used for ship's timbers and naval stores; live oak was used for ship building; decay resistant cypress and Atlantic White Cedar were prized for boat building and other uses. In North Carolina the majority of land in the eastern part of the state was wet (Lilly 1981a). North Carolina originally had an estimated 3.2 million hectares of hydric soils, excluding open waters. This is 26 percent of the land area of the state (Dept. of Environment, Health, and Natural Resources 1991). Estimates of the percentage of hydric soils in the forty two coastal plain counties range from 15.5 percent (Harnett) to 97.3 percent (Hyde), with twenty two counties over 50 percent (Table 1). Regardless of how wetlands are defined this represents a large amount of wet soils and wet forests. The swamplands shaped the way the land was settled and how it was used (Camp 1963). A number of economic, political, and technological forces have shaped the forested wetland resource we have today. Perhaps the best way to examine these forces is chronologically.

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ORIGINAL VEGETATION

At the time of colonization by the English, the sandier soils on the east coast were vegetated primarily in long leaf pine, maintained by fire. There were vast amount of such growth and much of it came to be used to produce turpentine and tar. By 1729 there was concern about the destruction of the long leaf pine forests (Hanlon 1970). Loblolly pine was less fire tolerant than long leaf and was primarily a tree of the swamps and a colonizer of recently cleared areas. The less sandy, flat, wet soils were in hardwoods, especially oaks and gums. This vegetative community, wet oak or hardwood flats, has been described as one of the most threatened and least represented wetland forest type remaining in North Carolina (Peacock and Lynch 1982). Slightly wetter swamps contained gums and cypress. The wetland type we call pocosin ranged form low scrub shrub to Atlantic White Cedar forest, depending mainly on the frequency of wildfire. Records indicate that there was probably considerably more Atlantic White Cedar at the time of first settlement than existed by the mid 1800s (Ruffin 1861).

Forest fires tended to maintain the long leaf pine communities, probably had little effect on cypress swamps, and helped keep the hardwood forests open. The old growth forest was more open than forests are now (Dept. Cons. and Devel. 1967). The cypress stands tended to consist of large old trees, indicating resistance to fire. Wildfires had the greatest effect on the pocosins. Atlantic White Cedar commonly emerges in thick uniform-aged stands after fires but is not fire tolerant. There are numerous accounts of pocosins leveled by fire. Ruffin (1861) records that all of the Juniper lands in the Great Dismal Swamp were destroyed by fire in about 1839 and that the area had not recovered by the 1850s. The Pettigrew papers (Lemmon 1971, 1988) contain many references to wild fires that raged in the pocosin swamps near Lake Phelps. Ruffin (1861) describes the area north of Lake Mattamuskeet in Hyde County as being a desolate place with no tall vegetation. Otte (1982) said that nearly all pocosins in North Carolina are of relatively recent development, and that the only two areas that appear to be relatively old are the pocosins of the southern Dare County mainland and the pocosins of Croatan National Forest. Dolman (1967) found much evidence of charcoal in organic soil profiles and deduced that infrequent fires tended to sustain the pocosin community and frequent fires caused it to spread. He also states that the "present vegetation is of little value in deducing natural features". Dolman (1967) estimated that the cropland in his study area had lost 178 centimeters of organic surface.

Based on the few records that do exist and the effects of more recent fires, it is my opinion that a considerable proportion of the original organic surface has been removed from lands in eastern North Carolina. As much as one half or more of the original peat is gone. This has strong implications for wetland restoration and reversion. For example, a site that has lost 178 centimeters of organic surface and is now essentially a wet mineral soil, cannot revert to a deep peat pocosin. This is not necessarily bad, just different. The organic swamps are really quite young geologically and appear to have developed only over the last 9,000 years or so (Oaks and Coch 1973). All peatlands and associated wetlands can be viewed as successional stages in a process of wetland development (Daniel, 1981). As organic debris accumulates, wet flats of gums or oaks would give way to species adapted to wetter environments, and these in turn are replaced by still other species. Once the organic accumulation is significant, indications are that fire frequency is the factor determining vegetative type.

EARLY EXPLOITATION

For the most part European settlers occupied the naturally better drained land and bypassed the swamps. The European population grew slowly for the century following initial settlement in the early 1600s, while the

Indian population declined. By 1729 the non-Indian population of North Carolina was only 36,000. Even so, competition for farm land was intense due to the constant need for new agricultural lands. Farming was based on slash and burn and all readily usable land had been farmed and abandoned or was in use. Governor George Burrington reported in 1734 that "...all the plantable land along navigable streams had been taken up" (Pomeroy and Yoho 1964). Population surpluses were exported to the frontier for the next several generations. Fire was extensively used in the land clearing process and it undoubtedly frequently got out of control. In addition, settlers intentionally burned the woods to encourage new growth for cattle grazing and to destroyed ticks that plagued the cattle. Cattle and hogs were allowed to range freely. Eastern North Carolina was a major livestock producing area and cattle and hogs had a considerable impact on the native vegetation. It was the landowner's responsibility to fence livestock out of fields. Cutting trees for fence rails was a major cause of forest destruction.

During this time public lands were under the control of the English government (Pomeroy and Yoho 1964). The Great Dismal Swamp of Virginia and North Carolina was the first formidable obstacle to development and the first place drainage on a large scale was attempted (Brown 1970). A group of investors, including George Washington, purchased 16,200 hectares in the swamp in 1763 (Brown 1970) with the intent to log it and develop it for agriculture. The Washington group never succeeded in developing farm land but they did construct the so-called "Washington Ditch" to Lake Drummond which still exist. Farming had begun around Lake Mattamuskeet by 1700, and it was general knowledge that drained swamp lands maintained their productivity longer than uplands (Ruffin 1861). Except for the swamplands and the steepest mountain slopes, essentially all of the present woodland in North Carolina and the South has been farmed and abandoned.

After the Revolutionary War, all unclaimed lands became the property of the state. In the east this meant mostly swamp land. The antagonism between the new United States and the English government prevented American investment in England. There was no industry in the new nation so speculative capital was made available for land acquisition, the purchase of slaves, and land development (Pomeroy and Yoho 1964). In 1790, 93 percent of the population was rural and many people made their living from the forests.

One of the first projects involving swamp land drainage was the construction of the Dismal Swamp Canal. This was a joint project between the governments of North Carolina and Virginia with the intent of opening up the Sounds of North Carolina to the port at Norfolk. The canal was begun in 1784 and completed in 1812 (Brown, 1970). The swamp was so much higher in its interior that locks were needed. The canal never revolutionized commerce between the two states as was intended, but it did open the swamp to logging and provided a means of transport for wood products. The spoil bank of the canal acted as a dam across the natural easterly flow of the Swamp and effectively drained its eastern part. As a result, that area was soon developed for agriculture. Ruffin (1861) records that by 1839 extensive and repeated wildfires removed the organic surface of the swamp to the extent that the buried ground logs were being harvested by loggers. Interest in the Great Dismal Swamp centered on logging with drainage and development an incidental side effect. In those early years the timber was often processed in the swamp and carried out as finished products such as wooden shingles.

The only land available for development in eastern North Carolina was swamp land. There was interest in rice growing, and it was believed that draining swamp lands reduced malaria. Also, the development of wetlands and lakes for agriculture in Europe was well known. The first large scale drainage project in North Carolina was on the north shore of Lake Phelps. In 1784 a group of investors acquired rights to about 68,850 hectares acres of land and obtained a state permit to drain the approximately 6480 hectare Lake

Phelps for agriculture in 1784 (Ruffin 1861; Redford 1988). A canal 9.7 kilometers long was dug from the lake to the Scuppernong River, beginning in 1789. Over the next seventy years the lands north of the lake were drained and cleared by several land owners. The original vegetation is described as great cypress trees, many growing over the buried trunks of older cypress (Ruffin 1861). Ruffin (1861) estimated that this swamp land had lost about 91 centimeters of organic surface by the 1830s.

Farming was important but logging of the cypress was a primary source of income. The first canal was followed by others, and there are references to the degree of drainage provided to the surrounding forested lands (Lemmon 1971). By 1822 Professor Elisha Mitchell wrote that across the state much land had been abandoned. There was a need for more crop land and the success of the Lake Phelps project as well as the successful farms surrounding Lake Mattamuskeet, led to speculative drainage of forested wetlands by the North Carolina state government.

In 1825 all state-owned swamplands were turned over to a state agency, the Literary Fund, to be used to support public education (Pomeroy and Yoho 1964). In a report dated 1827, it was estimated that the state owned about 607,500 hectares of swamp land (Kerr 1867). Beginning in 1838 the state attempted to make these lands attractive to buyers by digging primary canals at Pungo Lake, New Lake, Lake Mattamuskeet, and later, at Open Ground Pocosin (Ruffin 1861). Kerr (1867) estimated that 24,300 to 28,350 hectares of land were drained around Pungo and New Lakes, but that this drainage was insufficient for agricultural development. However, it undoubtedly influenced forest growth and the frequency of fire (Ruffin 1861). During this same period a canal was dug at Lake Ellis in Craven county (Lewis 1867) and land was cleared in the White Oak Swamp. The Albemarle Land Company acquired rights to 48,600 hectares of land from the Josiah Collins estate (in the central part of the Albemarle peninsula) and logged it from its headquarters in Pantego (Hanlon 1970). A large shingle mill producing hand-split shingle operated at Pantego before the Civil War. Until 1830 essentially all logging was done near water courses (Pomeroy and Yoho 1964). The Civil War bankrupted all state agencies and the state was urged to divest itself of all swamp lands to which it held clear title, estimated at 202,500 hectares.

LOGGING AFTER THE CIVIL WAR

Essentially all canals dug before the Civil War were dug by hand. Just before the war, the Pettigrew family was investigating the use of steam dredges on their plantation north of Lake Phelps (Lemmon 1971). Use of this technology was delayed by the war, but it was soon to reappear for use in large scale logging. Several large lumber companies with northern roots such as the Baird and Roper Lumber Company (eventually the John L. Roper Lumber Company) and the Richmond Cedar Works, began logging in the Great Dismal Swamp soon after the Civil War. Until 1870 lumber production had been relatively small and only the very best trees were cut. Pine was not acceptable if it did not have twelve inches of heart wood on the top end (Pomeroy and Yoho 1964). By the 1880s there was a considerable amount of interest in logging in northeastern North Carolina. By 1890 the original forest of the Great Dismal was almost depleted (Shaler 1890). According to Hale (1883) cedar (Atlantic White Cedar) was scarce but some cypress remained in the more inaccessible areas.

The logging railroad was in use by the 1880s. Over the next forty years all of the remaining virgin timber in the region as well as considerable amounts of second growth pine on abandoned farm land were logged. In the beginning lumber was unrealistically cheap and was widely used for purposes that demanded a more durable material, such as roads and sidewalks (Winters 1950). Even so, in the 1800s most of the wood harvested was actually used for fuel. A rise in timber prices after 1897 made it more economically feasible to

log the swamps and harvesting of forested wetlands accelerated. The Roper Lumber Company dominated the western part of northeastern North Carolina, and in 1907 owned 243,000 hectares of land and had cutting rights on 81,000 more (Hanlon 1970). The Richmond Cedar Works dominated the eastern part of the region and was estimated to have cut over from 405,000 to 910,000 hectares.

In 1883 Hale published a survey of the eastern forest lands of the state in which he said that Duplin and Pender Counties had the largest known bodies of cypress timber east of the lower Mississippi valley. Out of an estimated 534 square kilometers, the state owned 451. These were lands in Holly Shelter Swamp and Angola Bay Pocosin that had remained in state ownership since the Revolutionary War. These state lands have since been logged.

The great remaining resource at the time, though not for long, was in the region between the Albemarle and Pamlico Sounds. In 1894 Ashe estimated that out of 405,000 hectares of swamp there remained 16,200 hectares of white cedar but most of the cypress was gone and the land was being developed for agriculture. The area north of Albemarle Sound was nearly depleted by 1894 with only an estimated 3,240 hectares of cypress remaining out of an original 26,325 hectares. At the same time the great swamp forests were being logged, the remnants of the long leaf and short leaf forests were also being cut. There was immense waste and often only the very best trees were selected.

In addition to their Atlantic White Cedar business, the Roper Lumber Company is credited with developing a process for kiln-drying second growth southern pine (loblolly) so that it was acceptable to the northern markets. A high proportion of the Roper volume, as much as 80 percent, was second growth pine. White pine was becoming scarce, and second growth southern pine was promoted for its ability to accept paint. In 1907 the Roper Lumber Company was cutting 500,000 board feet of pine a day, plus 100,000 Atlantic White Cedar shingles and other wood products (American Lumberman, 1907).

DRAINAGE

Of course the resource could not last, and by the 1920s and the depression, essentially all the old growth timber was gone. Wetland forest logging began in the northeastern part of the state and moved south until other logging companies were encountered in the Cape Fear region. The wetland forests of the other states on the Atlantic coast were also being harvested.

Some of the cut over land was promoted for agricultural development but much of it was left to recover on its own. There was no reforestation but some concerned foresters were promoting the concept (Fernow 1911). Saw timber production peaked in the South in 1909 at 22 billion board feet (James 1948). Because of low yields, the need for animal feeds, strong exports, and an increasing population, more southern land was in crops in the late 1800s and early 1900s than at any time in history. This added to the pressure to open more land for agriculture. The interest in drainage led to the passage of a state Drainage Act in 1909 (Pratt 1909) that made possible the establishment of drainage districts with the power to levy taxes to pay for regional drainage projects. By these laws, drainage became a vested property right (Doucette and Phillips 1978). By 1911, twenty three drainage districts had been organized covering over 283,500 hectares (Pratt 1912). The drainage was intended to enhance agricultural production or reduce flooding, but as a side effect many acres of woodland were drained.

By the 1930s there was wide-spread abandonment of upland farm land across the south. Crop prices had crashed, mechanization was reducing the need for animal feeds, and the boll weevil had arrived. Soil erosion

was epidemic and interest in reforestation was growing. During the depression, government programs included tree planting on worn out farm land.

In the 1930s much of the cut over swamplands left by the "cut and run" loggers and the grown up farm land were acquired by the emerging pulp and paper companies. Land was cheap, pine was needed for pulp, and sustained production was needed. The first paper mill to use southern pine to make pulp was established at Halifax, North Carolina in 1909 (Goodwin 1969). The Halifax mill is credited with being the first operation to manage their wood supply, beginning in about 1927. The first North Carolina fire warden was hired in 1915 and the first tree nursery was established in 1925-26.

Log trucks began to replace the logging railroad about 1910 (Winters 1950), making access roads necessary. This, coupled with the need for access to suppress wildfires, led to accelerated drainage of forested wetlands beginning in the 1930s. Drainage canals were routinely constructed as part of the road system. It was pointed out as early as 1928 by Thompson that it was economically feasible to improve the growth of trees, such as loblolly pine, by drainage. Commercial forestry found the wet soils to be productive when managed, just as farmers had discovered some 300 years or more earlier.

In 1968 Teate reviewed the literature concerning wetland forest drainage, and traced the use in Europe. He stated that drainage specifically for enhanced forest growth was a fairly recent innovation in the southeastern United States. Teate did his dissertation work at the Hofmann Forest, which is an approximately 32,400 hectare wetland forest operated by North Carolina State University as a research forest. The acquisition and development of this forest parallels the acquisition and development of forested wetlands by the pulp and paper industry and mirrors the changes that have taken place in commercial forests.

When North Carolina State University acquired the Hofmann Forest in the 1930s it had been burned severely many times (Miller 1970) and access was very limited. Some canals were dug for drainage and logging by the CCC beginning in 1935. Prior to 1949 vehicle access was minimal. Starting in 1949, main roads and canals were constructed according to a plan. By 1970 (Miller 1970) the Forest contained 563 kilometers of roads and 805 kilometers of drainage ditches. More development has occurred since then. Over the years a great deal of wetland forestry research has been carried out here, especially on site modification and drainage, with substantial impact of the practices followed by commercial forestry (Maki 1974).

By 1978 Doucette and Phillips reported that about one third of the coastal plain was drained for agriculture or forestry. A USDA report (Pavelis 1987) shows that about 17 percent of all land in North Carolina is drained. Since 1950 virtually all the nation's large timber companies have purchased extensive tracts of land in the South (Healy 1985). Much of it is abandoned farm land (Healy 1987) but a substantial amount in some areas is cut over wetland forest. Cubbage and Curtis (1993) state that pine wetland types comprise only about 7.4 percent of the total 36,045,000 hectares of pine and pine-hardwood types in the South. However, they note that these are a crucial part of the most productive lands in some regions. The pond pine lands (pocosins) of Virginia and the Carolinas are mentioned as areas of special concern.

SUMMARY

Healy (1985) states that "The present southern forest is the product not only of natural forces but of four distinct kinds of human intervention: fire control, land clearing and abandonment, timber harvesting, and silviculture." With the exception of land abandonment, all of these forces have acted on the wetland forests. The southern wetland forests have been utilized for many years and some have been radically changed form

their original state. Virgin wetland timber almost does not exist.

Some forested wetland types have changed more than others, in particular the pocosins. Wildfires and natural oxidation after draining have caused much loss of organic surface. A change in organic depth or fire frequency will almost inevitably result in a shift in vegetation. Wildfire remains a problem in pocosins (Dean 1968) and over 405,000 hectares of pocosin on the Albemarle peninsula burned severely in 1985. The recent vegetation on a forested wetland is often a poor indicator of the historical vegetation.

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Table 1. **Percentage of land surface in hydric soils in the North Carolina coastal counties. Taken from: "Original Extent, Status and Trends of Wetlands in North Carolina". Report No. 91-01, Table 2, Department of Environment, Health and Natural Resources, 1991.**

County	Hydric Soils (percent)	County	Hydric Soils (percent)
Hyde	97.3	New Hanover	50.6
Tyrrell	95.5	Onslow	48.5
Dare	89.7	Robeson	47.0
Camden	89.6	Pitt	46.7
Washington	85.6	Duplin	45.0
Currituck	85.4	Hertford	40.2
Pasquotank	85.0	Lenior	40.0
Perquimans	83.4	Wilson	38.3
Carteret	83.0	Sampson	37.5
Pamlico	80.2	Edgecombe	34.8
Beaufort	71.4	Cumberland	33.7
Pender	68.5	Wayne	32.2
Jones	68.2	Halifax	30.0
Craven	66.8	Nash	29.5
Gates	63.4	Northampton	27.5
Brunswick	58.3	Scotland	26.7
Columbus	57.7	Greene	26.1
Chowan	54.8	Johnston	25.1
Bladen	54.1	Richmond	18.0
Martin	53.4	Hoke	18.0
Bertie	51.1	Harnett	15.5

HARDWOOD MANAGEMENT AND DRAINAGE: PAST PRESENT AND FUTURE

by

R. C. Kellison

Abstract.--Natural stands of southern bottomland hardwoods have been researched since about the end of World War II. The regeneration method having widest application is clearcutting. Because of environmental concerns and public perception, harvesting methods other than clearcutting are being implemented. Plantation hardwoods have been managed on a small scale since about 1960, but greatest emphasis was realized from 1970 to 1985. About 200,000 acres of plantations exist, with about 50,000 acres established in recent years, primarily on land being reclaimed from soybean production in the Mississippi River Delta. Future industrial plantations will be established on upland sites, on lands of highest quality and with intensive silviculture. Such lands will largely be immune from minor drainage. Minor drainage, other than that necessary for road construction and timber harvesting, for natural stands is also not considered feasible because alteration of the water table, either up or down, can have an adverse effect on timber production, and especially on reproduction.

Hardwoods are the predominant species in areas of the South that are today referred to as "wetlands" but which were formerly known as "bottomlands". In their primeval condition, these stands housed some of the best hardwood timber on the North American continent. Among the species of greatest occurrence were the oaks, ash, gum, sycamore, cottonwood, maple, birch, elm and hackberry.

Because of the difficulty of extracting the timber from the seasonally or perennially wet bottomland areas the early settlers found the timber resource to be more of a hindrance than a help to their way of life. With the advent of rice farming in the early 17th century much of the best timber was systematically destroyed, especially in the Lower Coastal Plain of the Carolinas and Georgia. In their place, a system of dikes and watergates was installed to allow for periodic flooding of the land. Such a system often prevented the regeneration of hardwoods until long after the rice farmers had abandoned their way of life. An aerial view of the area north and east of Savannah, Georgia still reveals the confines of the rice fields with wax myrtle, along the dikes, separating large expanses of juncas that were once the rice fields.

Further inland, where fresh water dominated the site and where seeds from upstream sources found favorable germination conditions, the abandoned rice fields were quickly colonized by hardwoods. Some of the best natural stands of hardwoods in the South, such as occur on Westvaco Corporation's Rice Hope Plantation in South Carolina, occupy lands that were in rice plantations little more than a century ago.

In the bottomlands of the Middle and Upper Coastal Plain, the farm crops were corn and cotton. To foster those crops, the procedure was to remove the timber and then to dike the area to prevent the overland flow of water. The best of that timber was used for houses and outbuildings, furniture, fences, farm implements and road and bridge construction, but the great majority of that bountiful resource was destroyed--girdled and left to die, or felled and burned. The timber closest to the river and its tributaries found a watery grave--anything to rid the land of impediments to agriculture. In the absence of inorganic fertilizers (which remained to be

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developed), the land was farmed until it lost its inherent fertility for row-crop production. Describing the conditions on his Center Hall Plantation on the Great Pee Dee River, near present-day Society Hill, in 1813, Governor David Rogerson Williamson of South Carolina told that the procedure was to "Cut down trees, clear and fence the land, grow crops for a few years, each year with less production than the year before, then give the fields up to weeds and briars, and finally to abandon them in quest of new settlements" (Cook 1916, p. 169). Today those lands, largely owned by Sonoco Products Corp., Hartsville, SC, support extensive stands of high-quality hardwoods. The novice would likely categorize these stands as "pristine" hardwoods, and would rail against the timber being harvested. A reality check occurs when lofty cherrybark oaks and other prime timber species are observed growing on the tops of the 12-foot high canals that exist from nearly two centuries ago.

WHAT OF TODAY?

Following World War II, the practice of forestry in the southern United States was largely devoted to pines, but enough interest in the southern hardwoods was engendered to start small-scale programs. The major emphasis was on regeneration and management of natural stands. The spurt of interest in hardwood plantations was delayed until about 1970, and it extended for about 15 years.

To manage natural stands of southern hardwoods for timber production we soon realized that certain species were associated with certain sites, and not with others. Those sites were also unique in their hydrology, geomorphology, logability and other physical, chemical and environmental attributes. To categorize those that are reasonably alike, and well as those that are different, we developed a class of forest site types (Kellison, et al. 1988). The seven bottomland forest site types identified for the Coastal Plain and the Piedmont of the southern United States are muck swamp, red river bottom, black river bottom, branch bottom, cypress strand, cypress dome and Piedmont bottomland (Table 1). The two site types involving cypress were included because they almost always contain a heavy component of hardwoods.

HARDWOOD REGENERATION

Natural Stands

Regeneration of bottomland hardwoods is best accomplished by clearcutting. Clearcutting, in this instance, refers to the removal of all merchantable timber, and killing the remaining trees by felling, girdling and poisoning. The practice has application to all forest site types of the bottomland hardwoods. It allows the ensuing stand to be comprised of both seedling and sprout reproduction. It is superior to alternative regeneration treatments because it allows the shade-intolerant species, nearly all of which are superior for wildlife and timber purposes to the shade-tolerant ones, to develop into the overstory part of the stand.

The notion that clearcutting is the preferred method of regeneration even in swamp hardwood forests resulted from the successes achieved following railroad and pull-boat logging, both of which used the high-lead cable system to draw the felled trees to the log deck. These systems penetrated into the deepest swamps, and they laid waste to all trees that had not been identified for log extraction. The regeneration that followed the devastation then evolved from a tangle of brush to healthy young stands, and eventually to the premier old-growth stands of today.

Alternatives to clearcutting include single-tree selection, group selection, patch clearcut, and seed tree, shelterwood and leave-tree cuts. Because of environmental concerns we will be using some of the alternative

treatments, even though they are more costly to apply, and they generally do not yield regeneration results as well as those from clear cutting.

The exception to an alternative being superior to clearcutting has been realized recently on streams with major impoundments. An artificial condition is created downstream from the dam where the soil water table is held higher than normal through the metered release of water from the reservoir. Since the reservoirs normally reach their highest levels during the late winter months the metered outflow extends far into the growing season. This inopportune timing coincides with tree regeneration, both from sprouts and seeds. The result is almost total regeneration failure of desired timber species unless advance regeneration (seedlings and sprouts greater than 4.5 feet tall) is present. They are supplanted by black willow, cattails, buttonbush, Virginia creeper and other non-desirable species. Preliminary results show that a shelterwood harvest is superior to clearcutting on one such site on a red river bottom in Alabama.

In natural stand management, the lesson learned is not to try to manipulate the water level, either through minor drainage or impoundment. Either type of alteration will have an adverse effect on the existing or the ensuing stand.

The green-tree reservoirs that were once common to the Mississippi Delta were thought to benefit the duck population while having no adverse, or even a positive, effect on tree health. Cumulative information, however, showed that the overstory trees, primarily of water, willow and Nuttall oak, would eventually decline in the reservoir condition, and that the regeneration following harvest of the parent stand would shift greatly toward the species commonly found on water saturated soils. The impact is more profound when the water is held on the green-tree reservoirs into the growing season. The reason is that the warmed water is depleted of oxygen, causing the loss of the fine roots which are instrumental in the uptake of moisture and nutrients. The irony of this situation is that the trees so affected die of drought while standing in water.

Similarly, major and minor drainage in and adjacent to natural hardwood stands causes a species shift from hydric to mesic or from mesic to xeric. Stands of swamp black gum adjacent to the Santee River in South Carolina are today being naturally replaced by red maple and loblolly pine as a result of a lowered water table from diversion of that water body into the Cooper River in the 1930s. Another species impact can be expected in the next 50 years from the rediversion of a portion of the water from the Santee-Cooper reservoirs back into the Santee River within the last five years.

Observations show that healthy semi-mature or mature stand of hardwoods can tolerate altered water tables for varying lengths of time: stands affected by a lowered water table might live for 50 years without observed decline whereas those affected by an elevated water table, such as might occur from impoundment, will show the effect in 6 to 8 years. In either situation, the impact on regeneration is immediate when the parent stand is harvested or is otherwise reduced to ground level, as might occur from a hurricane. Added impacts from the drainage of saturated soils supporting hardwood stands is soil subsidence, and the invasion of noxious exotic weeds such as Japanese honeysuckle and Chinese tallow tree.

Hardwood Plantations

A major effort of the Hardwood Research Cooperative at North Carolina State University[1] has been to conduct species-site trials on all the major forest site types in the South. The species that have shown greatest promise on each of the site types are shown in Table 2.

Efforts through the Hardwood Cooperative, the U. S. Forest Service and other public and private agencies were largely responsible for the establishment of about 150,000 acres of hardwood plantation in the South from about 1970 to 1985. Since then, another 50,000 acres have been added, primarily in the Mississippi River Delta on lands that were cleared of timber in the 1960 for soybean production. With minor exception, these 200,000 acres are restricted to bottomland sites, especially red river bottoms.

Within the last two years, interest has again been kindled for establishment of hardwood plantations for industrial use. This interest is largely separate from the effort in progress in the Mississippi Delta where the objective is wetland reclamation. The industrial thrust is to establish hardwood plantations on upland sites where the ensuing timber would be available without environmental restriction. Such stands will occupy the best upland (pine) sites, and they will be afforded high levels of fertilizers applied to a weed-free environment. The species of choice will initially be sweetgum and sycamore (for fiber crops), but additional species, including exotics, will be evaluated for subsequent use. Growth rates of 4 cords per acre per year are anticipated on rotations of 8 to 10 years. Some of the high initial establishment cost will be offset by two coppice crops in addition to the seedling crop.

This envisioned method of fiber production from hardwood plantations will obviate the need for either major or minor drainage. In its stead, irrigation could become a method of choice. Such an event, in combination with herbicide and fertilizer applications will necessitate monitoring of surface and ground water runoff.

It is perhaps obvious that not all hardwood plantations will be managed so intensively as I have described. Some organizations such as Weyerhaeuser Company and Federal Paper Board Company have been establishing sweetgum plantation in the Lower Coastal Plain of North Carolina for the last 20 years. Even though the annual acreage is small, the cumulative acreage is significant. The purpose of the plantations which are established and managed with the same technology used for loblolly pine, is primarily for fiber production and, secondarily, for wildlife corridors, fire breaks, pest management and landscape diversity. Such efforts will likely continue in conjunction with the allowable minor drainage associated with pine plantation forestry.

Exceptions to the high fertility regimes envisioned for fiber crops will also occur with high-value lumber species such as black walnut and cherrybark oak. These species will likely be planted in bottomlands on a small scale. They will occupy sites with good internal soil drainage, without significant need for minor drainage.

CONCLUSION

Minor drainage beyond that needed for road construction and timber harvesting in bottomland hardwood stands is not envisioned. Hardwood plantations will largely be established on upland sites; those to be established on bottomland or wetland sites will require silviculture comparable to that for pines. Natural

[1]The Hardwood Research Cooperative consists 12 industrial members and 3 public agencies with land holdings throughout the southern United States.

hardwood stands lose productivity and, especially, lose the ability to regenerate whenever there is either an increase or a decrease in water level over the normal.

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Table 1. **Bottomland hardwood site types by surface water classification and indicator species.**

Hardwood Site Type	Surface Water Classification	Indicator Species
Muck Swamp	Flooded 10 to 12 months	Baldcypress, tupelo
Red River Bottom	Flooded winter, spring	Sycamore, sweetgum, cherrybark oak
Black River Bottom	Flooded winter, spring	Tupelo, swamp black gum
Branch Bottom	Boggy throughout year	Swamp black gum
Cypress Strand	Flooded winter, spring, summer	Baldcypress
Cypress Dome	Flooded throughout year	Pondcypress, baldcypress
Piedmont Bottomland	Flooded winter	Yellow-poplar sweetgum

Table 2. **Hardwood species suited for planting on bottomland hardwood forest sites.**

Hardwood Site Type	Species	Method of Planting
Muck Swamp	Baldcypress, tupelo	Rice paddy technique
Red River Bottom	Cottonwood, sycamore sweetgum, ash, oak	Planting shovel, planting machine, seed sowing
Bottom	Sweetgum, ash, oak, baldcypress	Planting shovel
Branch Bottom	Yellow-poplar, ash	Planting shovel
Cypress Strand	Baldcypress	Planting shovel
Cypress Dome	Baldcypress, pond cypress	Planting shovel
Piedmont Bottomland	Sycamore, sweetgum, yellow-poplar, ash, oak	Planting machine, planting shovel, seed sowing

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TREE GROWTH AND SITE PRODUCTIVITY RELATIONSHIP TO MINOR DRAINAGE

William H. McKee, Jr.

ABSTRACT. -- With few exceptions, tree growth is retarded by flooding or inundation of soil for as little as a few weeks during the growing season. The degree of impact varies with such factors as tree species age, length of flooding, flowing versus stagnant water, soil texture, fertility, and competition. Under ideal conditions and with all other factors constant growth improves with increased moisture; however, after an optimal point, further increases begin to have a negative effect (Langdon and McKee 1980). Optimum productivity of a site requires management of these variables with the flooding characteristics of the wetland.

RESPONSE TO FLOODING

Tree growth response to dormant season flooding has been mixed. On river bottom sites, overland flow that drains before July lst has been shown to increase hardwood growth by 50 percent (Broadfoot 1967). McKee and Shoulders (1970) reported that a higher water table in winter decreased the growth of 6-year-old slash pine and lowered the observed redox potential. Langdon and others (1978) observed that a combination of high water tables in April, June, and July and lower water tables in May produced optimum periodic diameter growth in water tupelo. With few exceptions, flooding and soil anoxia during the growing season reduces the growth of all woody species (Kozlowski 1984). The degree of adaptation or tolerance to flooding depends on other environmental factors and on the physiology of the plant. This paper discusses the influences of tree age, stocking, nutrition, competition and bedding.

Interaction of Tree Age and Stocking with Drainage

Evapotranspiration within tree stands produces dramatic changes in shallow water tables throughout the growing season. By modelling loblolly pine plantations in the Coastal Plain of North Carolina, McCarthy and Skaggs (1992) found that stand development and silviculture significantly influenced forest hydrology. In average rainfall years, newly established stands only use about 18 percent of rainfall in transpiration, soil evaporation, and canopy interception. By age 15, stand use of rainfall reaches 75 percent, leaving only 25 percent for drainage and infiltration. In a study of the relationship between basal area and water table in the lower Coastal Plain of North Carolina, Langdon and Trousdale (1978) found that, loblolly pine stands growing in a 15 inch moisture deficit lowered the water table about one foot for every 40 square feet of basal area. The evapotranspiration effect is much smaller if an outside source recharges the ground water, as shown by Pearson and others (1993) for a hardwood stream bottom where the water table rose about 5 to 6 inches during the summer following a clearcut. Williams and Lipscomb (1981) found that partial harvests in pine stands on fine sandy soils raised the water table from 0.3 to 1.1 feet. This rise was most pronounced late in the growing season and persisted into the dormant season, usually until February.

These studies show that relating growth to drainage over a wide range of Coastal Plain sites is difficult, because the trees themselves are a major source of drainage. For instance, 60 to 70 year height growth data for loblolly pine in South Carolina showed that trees growing on better drained sites had convex height

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growth curves and trees growing on poorer, drained sites had concave height growth curves (Terry and Hughes 1975; USDA Forest Service unpublished data) (Figure 1). The implication is that the rate of growth begins slowly on poorly drained sites, but increases as the trees start to drain the site.

Interaction of Mineral Nutrition with Drainage

For sometime, forest scientists have tried to understand why some poorly drained sites are highly productive while others with similar drainage characteristics are extremely unproductive. Under normal fertility conditions, site productivity tends to decrease with increased flooding (Ellerbe and Smith 1961). Standing in contradiction to this general rule are the natural stands of loblolly pine growing on old rice fields of the Atlantic Coastal Plain (Gaiser 1950). The fields have site indexes over 100 feet, even though they are poor drained and have a 100-year history of repeated puddling, an agricultural practice that further retards water infiltration. Other sites with similar soil drainage may have site indexes of 40 feet or less. For loblolly and slash pine, the paradox appears to be partially related to the availability of phosphorus, a nutrient that seems to stimulate both the energy status of pine roots (DeBell and others 1984) and the detoxification of precipation-borne iron at the root surface (McKevlin and others 1987; Fisher 1989) Pine also develop aerenchyma tissue which can transport oxygen to the roots during extended periods of flooding (Hook and McKevlin 1988) -- a process that probably depends on enhanced energy status. The aerenchyma does not develop in the absence of anoxia. Langdon and McKee (1980) found that high quality sites typically contain phosphatic soils (Figure 2). On many low quality, poorly drained sites phosphorus fertilizer can increase tree height growth from 50 to 95 percent (Terry and Hughes 1975; McKee and Wilhite 1986; Pritchett and Llewellyn 1966). The combination of bedding and phosphorus application is additive, giving growth responses that equal the response of the two treatment effects added together. However, different species have different responses to fertilizer. Hook and others (1983) found that, unlike loblolly pine, swamp tupelo (Nyssa sylvatica) failed to grow faster with phosphorus application in a pot study. In an ongoing study of pine on some hydric sites, added phosphorus has failed to increase growth probably due to the limiting effects of other growth factors. This failure of pines to respond to phosphorus is typical of the ground water podzols (spodic soils) found on the Atlantic coast. In contrast, typical spodisols in Florida are generally responsive to fertilizer additions on established stands (Fisher 1984). These nutrient deficits may be present in other soil groups as well.

Although scientists have not yet established nutrient responses of other tree species adapted to hydric soils, observations suggest the existence of such interactions. River bottom sites that are flooded during the dormant season with of nutrient rich sediments produce high growth rates for adapted species. Hardwood stands growing on headwater swamps that do not receive nutrient rich sediments generally are unproductive and have limited diversity of tree species.

Interaction of Competition with Drainage

The interaction of drainage with interspecies competition is a subject of a study by researchers from the Southeastern Forest Experiment Station and Clemson University. Their results show that tree shelters alter competition and tree micro environment, thereby changing the optimum drainage by at least one Soil Conservation Service drainage class unit in terms of height growth. The study involved 12 hardwood species, three drainage classes, and three levels of native fertility based on geologic age of Coastal Plain terraces. Preliminary data suggest that the shelter treatment changed the optimum drainage from wet to dry sites for hydric species and dry to wet for some mesic species. The implication of these observations is that the absence of competition promotes growth of some hydric species on drier sites and some mesic species on

wetter sites. Thus the hydrophytic nature of an individual species can not be determined without considering the effect of interspecies competition. Terry and Hughes (1975) found that weed control for loblolly pine plantations resulted in a 64 percent increase in height growth on poorly drained sites, despite the tendency of weedy vegetation to increase evapotranspiration. This suggests that optimum productivity for a species -- as defined by its ability to grow a stand of trees -- may be more a function of controlling competitors than maximizing individual tree growth.

Interaction of Bedding with Drainage

Bedding influences tree growth, directly by improving microsite drainage over a wide range of soil conditions and indirectly through other factors that alter the tree's responses. Terry and Hughes (1975) reported that by concentrating top soil in the planting ridge bedding provided the same benefits as a fertilization. Bedding also controls competition especially for woody species. Bedding often prevents offsite drainage by blocking normal pathways and holding appreciable amounts of water in the bed furrows (Shoulders 1974). There is no indication that bedding changes the eventual cumulative tree growth (age 30 or 40), but it does change the shape of (convex and concave) growth curves (Wilhite and Jones 1981, Derr and Mann 1977). Bedding can improve early productivity, in terms of increased volume of wood per acre, substantially by increasing survival, regulating the rate of growth, and reducing competition. If beds are too large, the resulting drought conditions produce a decline in growth (Mann and McGilvery 1974).

RESPONSE TO FLUCTUATIONS IN FLOODING

For decades, scientists have tried to determine the optimum water table for seedling-to-sapling slash and loblolly pines. Shoulders (1974) found that drainage was needed in the West Gulf Coastal Plain when the water table in winter was less than 18 inches from the surface. McKee and others (1984) showed that loblolly pine grown on a poorly drained mineral soil in a controlled soil environment produced more biomass in two years if the soil was flooded to the surface during the dormant season than if the water table was at 24 inches year round. In contrast, White and Pritchett (1970) found that -- for the first 5 years of growth -- slash and loblolly pines fared better with constant water tables at 46 or 96 centimeters than with a fluctuating water table; the 46 centimeter depth was better than the 96 centimeter depth. Terry (1978) found that loblolly pine grew an additional 0.86 meters for each 15 centimeter reduction in the water table during winter and early spring (January to April). This model held true for water tables ranging from zero to 56 centimeters in Leaf, Lenoir, Bladen, Bayboro, Lynchburg, Rains, Pantego, and associated soils. Mueller-Dombois (1964) took a more theoretical approach using a controlled water table system in a greenhouse for 14 months. The authors concluded that growth was optimal when the capillary fringe came within a few centimeters of the soil surface, and that red and jack pines tolerated lower water tables better than black or white spruce. The capillary fring represents the height water moves above the water table by adhesive forces.

SUMMARY

Flooding-drainage properties interact with numerous site properties, which alter tree growth and stand development. Site conditions also change as stands develop and become a major factor in draining the site during the growing season. Therefore, the growth response of trees to flooding cannot be determined without considering stand age, stocking, soil nutrients, and competition. The interaction of these factors precludes the application of a single hydrological regime to all forest environments or even to one site over a forest rotation. Optimum hydrologic properties also change with changing management goals.

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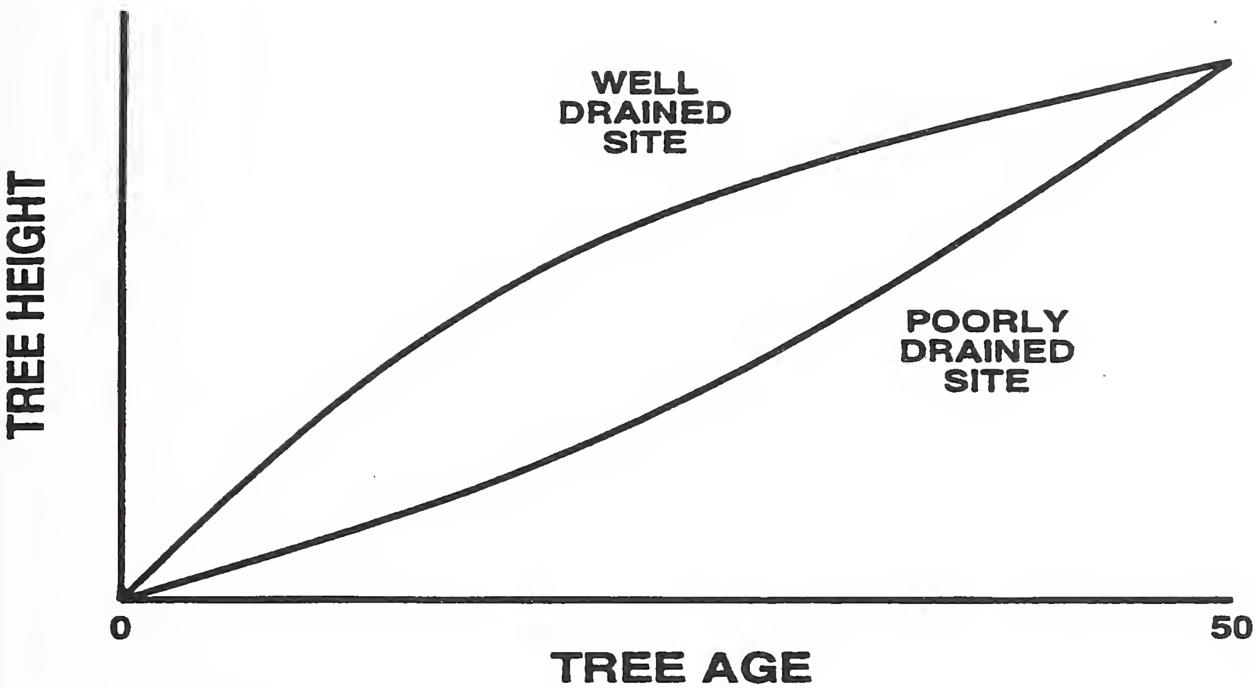

Figure 1 -- Idealized relationship of loblolly pine height growth over time with well and poorly drained sites. The relationship assumes other site variables are similar.

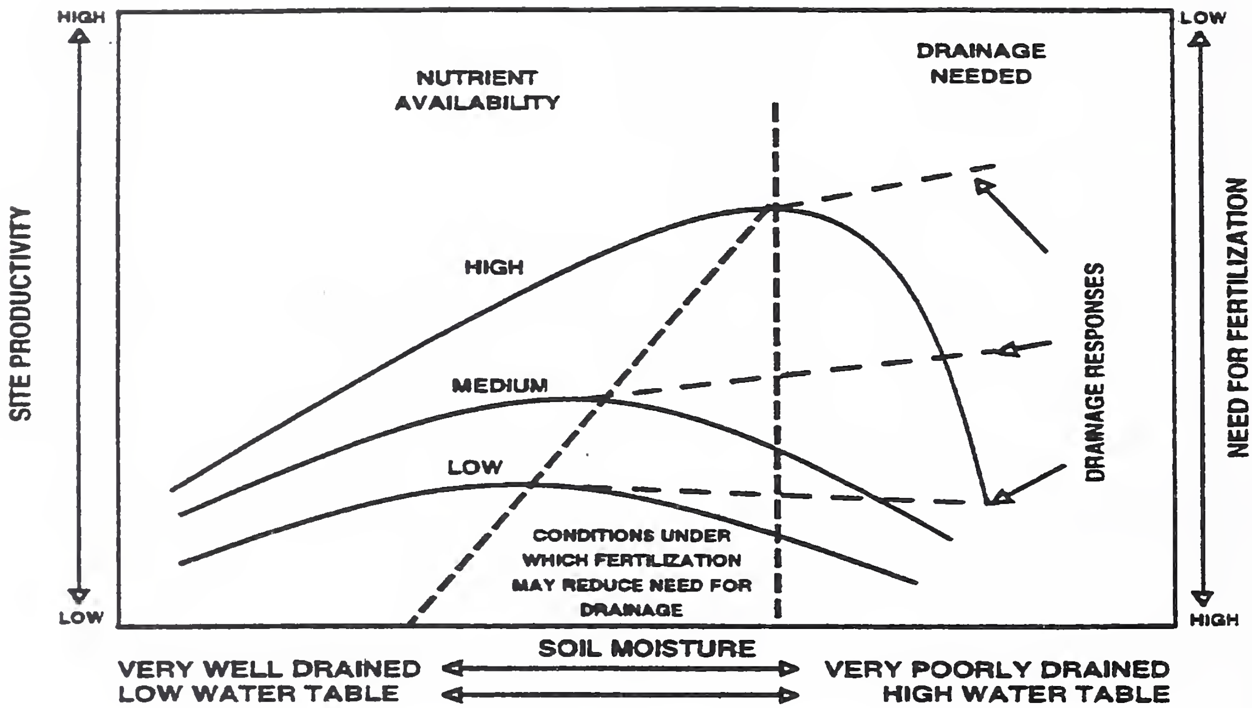

Figure 2 -- Hypothesized relationship of site productivity to soil moisture and phosphorus availability, the effects of drainage and fertilization, and conditions under which fertilization may reduce the need for drainage (Langdon and McKee 1980).

Wetlands Access Systems

Robert B. Rummer and Bryce J. Stokes[1]

Abstract

Access to wetlands is important for recreation, fire control, wildlife, harvesting, and other management activities. Increased public concern and environmental awareness have prompted improvements in access systems for wetlands. Road systems based on sound Best Management Practices (BMP's) and using new techniques for construction and maintenance of access corridors is one approach. Some innovative technologies and techniques to reduce roadbuilding are another strategy. Current research on these methods is reported in this paper.

Introduction

Forested wetlands are an important natural resource in the South, providing recreation, wildlife, timber production, and other values. Managing wetlands to maintain or enhance these values requires physical activities, or forest operations, to manipulate and interact with the ecosystem to achieve management goals. Thus, wetland access and transportation systems are an integral component of wetland management.

Access systems may range from all-weather roads, temporary spur roads, fire trails, wildlife corridors, skid trails, and recreational access. The selection of appropriate wetland access systems is dependent on a clear definition of management requirements. These requirements include:

(1) The type of forest operations that will be performed,
(2) The anticipated lifetime of the operations,
(3) Seasonal restrictions,
(4) Compliance with regulations (e.g. Section 404) and BMP's, and
(5) Loading levels.

Providing access to a wetland for hunting, for example, defines access requirements such as continuing use, open in several seasons of each year, light traffic loads, and a certain road density. Access for timber extraction, on the other hand, defines another distinct set of requirements: once-a-rotation use, heavier loads, dry season access, and a closer road spacing. For any given management unit, access requirements may involve a combination of objectives and constraints.

The overall goal of wetland access selection is to provide the necessary forest operations onsite, at the lowest cost to the management unit, while accommodating and protecting the ecosystem for sustainable resource use. Thus, the resource manager must understand the access requirements and the various alternatives that can be implemented when planning wetland management.

Wetlands are a major source of hardwood timber supply that are dispersed over fragile sites often difficult to access. Objectives in managing these ecosystems are to provide access to the timber resources, assure continued site productivity, and conserve all other nontimber resources on such sites. Access to trees for

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timber extraction and roadbuilding are two of the most intensive activities with the greatest potential for ecosystem disruption.

New technologies and techniques are being developed to attain access and to manage the resources on these sites. Current state-of-the-practice wetland roadbuilding methods that can be compatible with other ecosystem values are described here. In addition, some alternatives to conventional roadbuilding are explored.

Roadbuilding

Wetlands are important ecosystems in the general hydrologic cycle because of the functions of filtration and water storage (Preston and Bedford 1988). These wetland functions improve water quality and provide a buffer for drainage from adjacent upland areas. The effectiveness of the wetland is dependent on water flow patterns and chemical interactions between the water and the site. Roadbuilding in wetlands is a significant stressor since it can affect both hydrology and water quality.

Roadbuilding can alter site hydrology by disrupting normal surface and subsurface flow patterns. A raised roadbed, for example, may act like a dam impounding water on the upstream side of the road and raising the local water table. Conversely, a ditch cut along a road may intercept subsurface flow and lower the water table on the upstream side of the road. The difficulty in avoiding such consequences is compounded when the site experiences wide variations in flow and lacks clearly defined drainage patterns. Alterations of site hydrology may also affect water chemistry by influencing relationships involving nutrient exchange between floodwater and the floodplain (Patrick and Khalid 1974).

Roadbuilding is also implicated as a significant source of sedimentation associated with forest operations. Sediment can be generated from disturbed, exposed soil in the road right-of-way and cut and fill slopes, from fines produced on the running surface by traffic, from concentrated flows in ditches and around drainage structures, and from soil disturbance resulting from routine maintenance such as ditch clearing (Burrows and King 1989). Several studies indicate that increased sediment yield associated with road construction diminishes to near baseline levels in the first few years after construction. Road maintenance, on the other hand, produces sediment periodically over the life of the road.

Wetland Roadbuilding Guidelines

Most of the Southern States have non-regulatory programs that include Best Management Practices (BMP's) that provide guidelines for forest operations to protect water quality. Alabama, Georgia, Florida, Kentucky, Louisiana, Mississippi, South Carolina, Tennessee, Texas, and Virginia have additional specific wetland BMP's including road construction. Because these documents are derived from Federally mandated roadbuilding practices for jurisdictional wetlands, many of these documents provide similar information. Jackson (1992) provides a summary of wetland road construction guidelines.

Due to the potential impacts associated with roadbuilding in wetlands, all BMP's emphasize planning. Actual access requirements must be carefully studied to avoid overbuilding the wetland access system. The planning must anticipate the type and timing of ecosystem manipulations that will use the road. For example, continuous timber extraction under an uneven-aged silvicultural system may require more extensive permanent road structures than would an area managed on an even-aged basis. Similarly, if the unit will provide wildlife, hunting, or ongoing recreational activity, all-weather roads may be required. Planning can minimize the total length of roads, as well as reduce road construction in sensitive spots such as stream and slough crossings and soft soils.

When roads must be constructed in wetlands, guidelines recommend minimum cross-sections (i.e., a low crown and shallow ditching) to reduce potential ponding. Adequate cross-drainage is also important to avoid ponding and can be provided through dips, relief culverts, and natural drainage features. Culverts are commonly specified in wetland road construction guidelines for cross-drainage, yet there are two significant considerations that are often overlooked--sizing and maintenance.

Culvert selection usually involves estimating the size based on a large stormflow. These design procedures have been well developed through application on upland sites to avoid culvert washout and failure (Georgia Forestry Association 1990). In many wetlands, however, annual flooding events may completely inundate the drainage structure. In these situations, the culvert installation should be designed with additional features. For example, the lowest portion of the road crown near the culvert will act like a spillway when the flood flow exceeds the capacity of the culvert. This portion of the road should have special consideration in the form of vegetative or structural stabilization to avoid washout.

Cross-drainage through culverts on permanent roads also requires an ongoing maintenance commitment. Culverts may become blocked as a result of debris or sediment accumulation, mechanical damage during road use, or beaver activity. The culvert maintenance program must be able to locate all culverts (staking can reduce search times) and clear blocked culverts with a minimum of site disturbance. Florida's BMP's recommend periodic checks on drainage structures, particularly after large rainfall events. Immediate corrective actions are required when drainage failure is observed (Anon. 1993).

A wide range of alternative drainage structures has been developed for wetland access. The Florida BMP guide describes the advantages of hard-bottom crossings (fords) in wetland situations. Broad-based dips, originally developed for upland roads, can also be used for wetland cross-drainage structures. Taylor and Murphy (1993) and Mason (1993) describe the design and application of portable, reusable crossing structures such as timber bridges and pipe mats.

While proper cross-drainage can avoid problems of impeded flow, sedimentation concerns are primarily addressed through vegetative or structural stabilization. Structural stabilization such as rip-rap may be necessary in areas where large flow volumes are anticipated (i.e., culvert inlets and cross-drainage dips). Areas of disturbed soil such as shoulders and the right-of-way clearing where water velocity is low may be adequately stabilized by seeding and fertilizing.

The roadbuilding guidelines cited above can address many problems associated with roads in wetlands. Research questions remain, however. Federal guidelines require removing temporary access structures. This is interpreted in different ways in the State documents. Tennessee, for example, specifies removing all temporary fills and reconstructing the roadway to its natural contours. South Carolina, however, specifies only the removal of temporary culverts and bridges and cross-ditching of the abandoned road prism. While such activities may eliminate drainage problems, they may also introduce additional sediment into streams. Research is needed to examine the impact on the ecosystem of the use and abandonment of temporary access.

Low-impact Access

There are several alternatives to conventional roadbuilding for low-impact access that are currently in various stages of development or application. Some are only concepts, but many are used operationally on a limited basis in non-wetland timber production. High-standard roadbuilding is generally more disturbing to the site than harvesting. In addition, high-standard roads are expensive to build and maintain. Alternatives include

the use of special equipment that can transport timber on low-standard roads or transport the wood farther without the use of roads.

Matting is a method of using low-standard roads for transport. Wooden mats are laid down as a road surface to provide traffic support and reduce the amount of subgrade required. Mats are retrieved after access, leaving little residual disturbance. Specialty matting and mat-handling equipment may provide access to more difficult sites. However, current matting is a cumbersome, unsophisticated method of wetland access and is thus unsuitable for general application. Further development in mat materials and methods is required before mats are a viable alternative.

Another access option is central tire inflation systems that allow transport vehicles to use lower tire pressure. Lower tire pressure reduces road degradation under traffic loads. Studies on upland sites have shown that lower tire pressure can reduce sediment generated on logging roads (Foltz and Burroughs 1991). Lower tire pressure also allows road designers to specify thinner subgrades, a requirement of many wetland BMP's. Finally, lower tire pressure can reduce road maintenance requirements such as periodic grading.

Large forwarders have been introduced in wet areas and steep slope logging and have had some success (Jackson and others 1990, Stokes and others 1992). Studies of wide-tired forwarders in eastern Canada have found: (1) increased access to wood without roadwork, (2) improved stability, safety, and comfort, (3) adaptability to wet season logging, (4) less maintenance and more productivity because of their flotation ability, and (5) reduction, if not almost elimination, of residual damage to the site. Tree-length forwarders can move large loads while exerting a low ground pressure. This type of machine has exceptional value for moving wood long distances. Large payloads reduce the number of passes required on the same trail. Clambunk skidders have been used successfully in similar applications.

Cable systems and helicopters have been used in wetlands on a very limited basis. The primary advantage of these systems is a reduction in site disturbance. Disadvantages are higher costs and specialization of the operation. The proper cable system can be a solution to the problem of extracting wood from wet sites with minimal impact. An important feature of a successful system is giving the logs high lift, even to the point of keeping them completely off the ground over a longer distance using intermediate supports. Another requirement may be portable tailholds for quick setup after moving. On large, flat tracts such a system may be environmentally preferable to building access roads. Since this concept is unproven, it is generally considered too expensive. However, for problem areas where low soil strength precludes the use of ground-based systems, the only means of removing trees from many sites, other than by helicopter, may be a cable system.

Helicopters are being used more frequently on wet sites (Willingham 1989). This system causes the least disturbance of all timber access systems, though log landings may be somewhat larger than in ground-based systems. It may be cost-effective in certain situations, but it is not the answer to all the problems of harvesting wet sites.

Another new concept is that of towed vehicles, especially if combined with a specialized felling and short-distance piling (shoveling) machine. If traction is provided by a drum at the roadside, then specially designed, lightweight vehicles can carry more wood and cause less rutting. Since slip is zero, soil movement is reduced. In-woods machine flotation can be increased by removing the weight of power units or reducing engine size to meet only travel empty power requirements. Such vehicles can be driven out and towed in, or towed both ways. They can be manually operated or remotely controlled.

Other methods may include innovative lift devices, such as balloons or air cushioned vehicles (ACV's). Balloons can be used when ground-based logging is impossible due to low soil strength. Although the concept is feasible, it has been only marginally economical (Trewolla and McDermid 1969). Balloon costs have been prohibitive to date, but in the future, their advantages may offset many costs. Balloons can be either tethered and controlled by cable systems or free flying with remote-controlled propulsion and guidance systems. There are some recent developments in the use of such lift devices that have promise, especially if used in combination with other innovations such as shovel felling/piling or matting.

Air-cushioned vehicles have proven capabilities of wetland access in military applications. The load on an ACV is evenly distributed over the entire ground surface beneath the vehicle. Because of the light, uniform loading, site impact is minimal. ACV's can be towed or self-propelled. If combined with a cable and drum set, for example, a full barge of trees can be floated across wet sites, streams, swamps, etc., reducing the need for access construction. If used with towing machines, such as skidders, ACV's can transport wood over unimproved skid trails instead of building haul roads. More research is required to completely understand these options and to properly select and apply the technology as it is developed

Summary

Landowners, loggers, and resource managers considering access for wet sites are confronted by a range of constraints due to the unique nature of the wetland ecosystem. Conventional systems used successfully on upland sites are not always adapted to wetland applications. Standard practices designed to reduce adverse site impacts on uplands may not be effective in a wetland hydrological system. Therefore, it is important that resource managers understand the potential impact of various wetland access systems. Through proper selection, planning, and application of access and roadbuilding, ecosystem values can be maintained during management activities.

The forest industry is aware that new, innovative methods must be developed and implemented that result in minimum site disturbance while still being cost-effective. Some of these concepts have particular applications where they will excel when considering tradeoffs among all values. More research is required to completely understand the options and to properly use new technologies.

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DRAINAGE CASE STUDY - WESTVACO CORPORATION

Robert J. Fledderman, Westvaco Corporation

I'm Bob Fledderman, a forester with Westvaco's Timberlands Division. Westvaco is a major producer of paper, packaging and specialty chemical products with domestic paper mills in Charleston, SC; Covington, WV; Luke, MD; Wickliffe, KY; and Tyrone, PA. I've been involved in various capacities of land management for Westvaco for the last 17 years. Currently, I am the Environmental Manager for the Timberlands Division, which has land management operations primarily in Kentucky and Tennessee; Virginia and West Virginia; and South Carolina.

Before I start, I'd like to emphasize that we believe our drainage activities qualify as minor drainage in that our drainage systems only remove excess surface water except for a small area immediately adjacent to a ditch. In keeping with the spirit of this workshop, however, I have dropped the phrase "minor drainage" since we are here to define what it is.

I'm here to present two case studies on surface water management. The first is on a pineland parcel in South Carolina. The second is on a bottomland hardwood site in Kentucky. Before I get into the specifics of these cases, I'd like to discuss some of the reasons why removing excess surface water is so important to our forest management operations.

Forest Land

In general, forestry gets the land that others don't want. On the scale of economic uses for land, timberland is toward the bottom. We get the land that is "too" something. It's either "too" remote, "too" steep, "too" infertile, "too" wet; or some combination of the above. In the South Carolina coastal plain, our lands are frequently wet and often infertile. In order to make these lands economically attractive for timber production, some investments in improvements are often needed. Drainage has been one of the key investments we have made. Often our drainage projects were designed and supported by the Soil Conservation Service which has helped thousands of rural landowners in South Carolina with drainage projects from the 1950's into the late 1980's.

Access the Key

One reason for drainage in forestry is to assist in the establishment of young stands. Drainage is necessary after the normal hydrology is affected by the removal of the trees during harvest. But perhaps equally important is the need to improve the access to our land during winter and early spring. Drainage does improve both growth and survival of crop trees; however a greater portion of the increased growth comes from the indirect benefit of better access for reforestation and protection from wildfire than it does from the direct benefit of more favorable soil hydrology conditions. Improved access also extends the periods when timber can be harvested, which is a very important concern for every pulp mill.

Wildfires are a serious concern for timberland managers in the coastal plain. Our most difficult wildfire season is during late winter and early spring when the ground is often saturated. Our fire fighting strategies are based on getting to a fire quickly over permanent forest roads. In the past, fires have destroyed large areas simply because they were roadless or the roads were too wet. Without drainage, many of our forest

roads would be inoperable during significant portions of the year.

Establishing plantations requires access during the winter months. Drainage is necessary to remove the excess surface water to plant trees and to limit ponding during the first few months after planting, when the seedlings are especially vulnerable. Drainage systems act as relief valves. They provide outlets to remove excess surface water before the water overtops the beds. Drainage improves seedling survival, it is often the difference between a poorly-stocked stand and a well-stocked stand.

Timber harvesting operations need to continue during the wet winter months for at least part of the time. To operate economically, pulp mills must run continuously, 24 hours a day, 365 days a year because they are very expensive to stop and start. There are also limits on how much wood can be stored. Wood in inventory must be used before it spoils. Loggers have limited financial resources to weather extended periods of downtime. Modern loggers often have more than $500,000 of capital tied up in their equipment. They can afford to be without work for short periods, but being out of work for months would bankrupt many of them and cause extreme hardships for their employees. Drainage systems usually extend the periods when ground conditions and forest roads are capable of supporting harvesting equipment. This is especially important near the "decking areas" adjacent to roads where logging traffic can quickly churn saturated soil into a quagmire.

Winter and early spring is a critical time for forest management. Besides planting and wildfire control, other activities such as prescribed burning and competition control also need to be performed during the cool months when the trees are dormant.

Drainage Systems

Drainage on our forest land is often more than a single ditch. Most of our land is composed of relatively large contiguous blocks. Our drainage ditches often tie together into a system, eventually moving the water to one or more outlets. Outlets are the key to the system. We need to be able to move the water from the collector ditches or secondary ditches to a point lower on the landscape. That means the collectors must be connected to the outlet by conveyor ditches or primary ditches. Some of our drainage systems are dug in a pattern because the whole area is relatively flat. More frequently, where there is some dissection in the landscape, drainage systems are more prescriptive, following the concave parts of the landscape. Some people refer to this type of drainage as pond-to-pond drainage.

Drainage Ditch Specifications

Our drainage systems are designed to remove excess surface water. I say that because some of our original drainage efforts were aimed at controlling subsurface water. But these ditches failed. Experience taught us that the influence of our ditches on the water table was very limited, a modest water table change that extended less than 100 feet to each side of the ditch in most situations. To install drainage systems to control the water table would have been prohibitively expensive both in terms of the costs of construction and the amount of land taken out of production due to the density required.

In addition, we found that the trees themselves, once they were well-established and actively growing, dwarfed the impact of our drainage systems on the water table through evapotranspiration. In our initial drainage systems, water control structures were installed to hold the water during dry periods. However, even when the flash board risers were in place in a timely fashion, it was only a matter of days before the evapotranspiration of the trees dried up the ditches.

Secondary Ditches

Secondary ditches are placed a quarter mile or more apart in a patterned drainage system, depending on soil and topographic conditions. In prescription drainage, the secondary ditch spacings are not defined, but usually they are less dense than in a patterned drainage system. Secondary ditches are dug between 3.5 and 4.5 feet deep. We find these dimensions are sufficient to overcome microtopographic variations, allow for some sloughing on the sides, and are deep enough to continue to be functional if some vegetation is established on the bottom of the ditch. They are also deep enough that some water frequently stands in the bottom most of the year. The water acts as a natural cultivator, extending the life of the ditch.

Primary Ditches

Primary ditches are constructed to handle anticipated water flows from the secondary ditches. Where permanent roads cross primary ditches, culverts or bridges that have sufficient capacity are required.

Case Studies

South Cain Bay

South Cain Bay is a 4000 acre parcel located in the lower coastal plain of South Carolina just south of Lake Moultrie. It is in the upper reaches of the Ashley River watershed on a landform that evolved from sediment deposited behind a former barrier island. The parcel is in an area commonly referred to as a broad interstream divide. This landform occurs between two drainage systems, in this case the Wassamassaw Swamp to the northwest and the scarp running down to the Cooper River to the southeast. The small bluffs adjacent to the drains are better drained then the land between the shoulders. Water input is by rainfall only, as there are no streams to overflow. Natural drainage in the interior is very slow because the terrain is flat and soil textures are typically loamy to clayey. Gum ponds and other slightly concave features are scattered on the landscape, but incised water-carrying channels are absent. South Cain Bay's soils are characterized by the Soil Conservation Service as poorly and very poorly drained; that is, their natural internal drainage is slow, and shallow water tables are at or near the soil surface during winter and early spring.

South Cain Bay's natural site productivity is lower than average, but its soils are responsive to additions of phosphorous. We believe that most of the soils on this tract are also responsive to nitrogen.

Natural vegetation was scattered pond pine with a thick understory of plants like bitter gallberry, fetterbush, greenbriar, sweetbay, Ti-Ti, and wax myrtle.

After several significant fires on the unit in the mid-1950's to mid-1960's, Westvaco decided to improve access to South Cain Bay by investing in a drainage and road system. Primary ditches were dug in the late 1950's, while the secondary ditches were added in the 1960's. A water control structure was installed at the north end but was abandoned after several years because it was ineffective.

This parcel is one of the sites where an attempt was made to influence the water table with drainage. The patterned drainage on this tract is as dense as any we have. However, as mentioned earlier, the density was not nearly close enough to have the desired result of controlling the water table.

One of the reasons I selected South Cain Bay for this case study is that a research study was established on it

in 1983. Part of that study included monitoring several lines of water wells that run perpendicular to the ditch adjacent to the study. A graph of the data from these water wells gives us some idea of the water tables on the site as they are influenced by the drainage system and the evapotraspiration of the trees and other vegetation. The graph indicates that subsurface water is not affected beyond 100 feet by the secondary ditches and that the influence of the actively growing trees and other vegetation is the dominant force impacting the subsurface water table during the growing season.

Once wildfires were controlled with the help of the improved access, most of the tract was planted with slash pine which is now being harvested and reforested with loblolly pine.

The change from natural stands to plantations with site preparation, genetically improved seedlings, good density control, fertilization with phosphorous and herbicide applications to reduce competition during the critical months after planting is estimated to increase yields from this parcel five fold.

Stovall Creek

The Stovall Creek case concerns hardwood management. Although this particular tract is in Kentucky, the situation is universal where bottomlands occur in relatively flat, wide landforms.

Nearly all of the large creeks and small rivers in Western Kentucky and Tennessee have been channelized in the past, many with government funded public works projects. The straight dredge channels did not follow the lowest point in the flood plain. This fact, combined with sedimentation, the lack of maintenance of the dredge channels, and beaver activity, has resulted in large scale destruction of bottomland hardwoods.

The channelized portion of Stovall Creek drains a 5000 acre mixed upland and bottomland watershed into Mayfield Creek, about 6 miles from the Mississippi River. The channel was blocked with assorted debris. These blockages are common and can form rapidly or gradually. In this case, we noticed the impoundment behind the blockage was beginning to affect surrounding stands before the damage occurred.

Typically these stands are well-adapted to dormant season flooding, but they can be destroyed in a short time by impounded water during the growing season and by scouring over-land flow during storms when channels are blocked.

Active management, including drainage activities, is required to prevent conversion to open water and the destruction of the bottomland hardwoods.

We decided to re-direct the channelized section into the old meandering channel above the blockage and to dig a pilot channel following the meanders. It would require a minor amount of excavation. The purpose was to restore natural hydrology and protect an existing bottomland hardwood area. However, after discussing the project with the Corps of Engineers, and being advised that it did not qualify as minor drainage, we applied for a permit. It was September 1992. After ten months of back-and-forth negotiations a permit was granted.

The pilot channel was constructed. We left one bank undisturbed and spread the dredged material to prevent a berm or levee. The banks were seeded and strawed.

The first few storm events expanded the pilot channel without changing its meandering course, exposing old

woody debris and creating the pools and riffles of a natural stream bed. We have since removed some blockages involving fallen trees in order to stabilize the channel.

This project was successful. But we believe the costs and frustrations associated with individual permits for these projects are causing a retreat from active management of these forests and leading to continued losses in not only timber values but wildlife habitat and other benefits associated with healthy bottomland hardwoods.

Summary

On the coastal plain, the timing of many of our cultural activities requires access during the winter and spring months, when excess surface water is frequently present. Drainage systems are critical to providing that access.

In bottomland situations, stream blockages can cause the destruction of bottomland hardwood forests, in some cases even convert the bottomland forest to open water. Reestablishing natural drainage is necessary to save the timber that many landowners may have been nurturing for decades.

Thank you for asking Westvaco to participate at this workshop. I hope these remarks and case studies help convey the importance of drainage to the forest community.

APPLICATION OF MINOR DRAINAGE ON NON-INDUSTRIAL PRIVATE LANDS

John B. Sabine

Abstract.-- Minor surface water drainage is used by private non-industrial forest owners to manage water during harvest, site preparation, and early stand development operations. Reducing soil saturation for the first few years after planting is critical to proper root development. Surface water drainage is also used to reduce the impact of heavy rains on farm field operations.

INTRODUCTION

The southeastern United States has always been a center for softwood timber production. The long growing season, mild winters, fertile soils and abundant water availability make it an ideal area for intensive timber management. Recent developments that have restricted timber harvesting in the Pacific Northwest have resulted in a rapid increase in demand for southern pine wood products and a corresponding inflation of prices. After several years of low interest in forestry investment, recent months have seen a surge in activity involving timber land purchase for long term investment.

At the same time, there is increased pressure on the timber industry and private non-industrial owners to manage their lands in an environmentally sound manner. Water quality, endangered species, landscape management, ecosystem management and biodiversity are all terms and concepts that are being considered in management plans written by foresters today. Timber sale contracts all require strict adherence to Best Management Practices (BMP) and increasingly strict regulatory overview has resulted in significant improvement in standard silvicultural activity. There is a heightened awareness and critical review of forestry operational procedures. One of the offshoots has been the voluntary preservation by industrial and private owners of many ecologically unique and sensitive areas.

The influx of people to the South and the need to provide them with housing and services has also contributed to a reduction in the land base available to grow timber. Quite often, some of the best agricultural and forestry land end up covered with asphalt. The result of this pressure on the land base is that fewer and fewer hectares are available to meet the demand for growing wood fiber. This means timber will be managed on the best sites with heavier reliance on fertilization, pest management and genetic improvements to help shorten rotation age. Riekerk and Koshnak (1984) suggest that pine management in the Southeast will soon be performed with the same intensity as agriculture.

Some of the most productive areas for pine management are characterized by poorly drained soils (Nutter and Gregory 1985). In the southeastern United States, these areas include over 242,915 hectares of pond pine (Pinus

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serotina), 283,286 hectares of slash pine (Pinus elliottii), and 485,633 hectares of loblolly pine (Pinus taeda L) in the South (Cubbage and Flather 1993). Managers have long recognized the superior fertility of these areas and vast acreages were cleared, drained and planted with pine in the past. Cubbage and Flather (1993) also suggest that "while the wetland plantation area may be modest overall in the South, it is a crucial part of the most productive lands in some regions."

WATER AND TIMBER STAND ESTABLISHMENT

Poorly drained areas have in the past been looked upon as wasted space. Massive drainage efforts have been launched to make these wetlands "productive" and useful to mankind. The Georgetown County Drainage Commission Report (1979) says "Poorly drained soils adversely affect the use of the land for most purposes. On agricultural land high water tables restrict root depth; the soil temperature is lowered and air circulation is severely limited depending on the degree of soil saturation." This report goes on to discuss the fact that farm operations can be delayed and growing seasons shortened by "wet spots in the field".

The Clean Water Act of 1977 (CWA) began the efforts to stop the massive destruction of wetlands with huge canals and drainage systems. Forestry and agriculture were granted certain exemptions in Section 404 (f)(1) of the CWA. The silvicultural tool this case study addresses is the minor drainage of surface water.

There have been many studies that have looked at root zone saturation and tree growth. McIninch and Biggs (1993) reported an inverse relationship between root growth and soil saturation. Campbell and Hughes (1991) recorded a 3 to 5 meter increase in base age 25 year site index due to drainage of pocosin areas. Wilhite and Jones (1981), in a study investigating bedding effects on slash pine, discovered that ditching resulted in an increase in total height at 45 years over an unditched site. These studies point to the importance of controlling water in the root zone during establishment of a stand of timber.

Bedding is another management tool used to move the roots of seedlings out of the zone of soil saturation. Wilhite and Jones (1981) showed that bedding increases growth in the early stages of stand establishment. Haywood (1983) discusses the need to properly orient beds with drainage to achieve the maximum advantage of both systems.

Another water management concern that is often overlooked by managers is the impact of timber cutting or vegetation removal on the water table. A mature conifer can transpire over 4,000 liters of water during the summer (Hinckley, et al. 1978). If the timber is harvested and the transpiration rate is decreased, the water table will rise. Williams and Libsomb (1981) measured a rise in water table that ranged from 1.1 to 3.5 meters. This rise in water table will quite often last into the dormant season (William and Liscomb. 1981; Riekert and Korhnak 1984).

Typical timber management in the coastal plain includes drainage (Nutter and Gregory 1985). Campbell and Hughes (1991) reported that pine plantations with free drainage can have water tables .30 to .60 meters lower than undrained plantations. Soil saturation still occurred but fluctuations in the water table were dampened. They also felt that "Forestry drainage does not change the basic hydrologic cycle or affect conversion of wetlands to uplands but increases the length of time the surface soil is in an unsaturated condition." Debell, et al. (1982) reported that surface drainage in wet areas could be used to create conditions suitable for survival and growth of pine.

Timber managers faced with increased pressure to grow more fiber on less land are looking for techniques and tools to help them accomplish this. They utilize data and years of experience to forecast that cutting a block of timber in a low wet area is going to result in a rise in the water table. This will adversely affect the operation of machinery for site preparation and may cause longer duration soil saturation which could result in seedling mortality or decreased vigor. How should the manager address this problem? The objective is to remove the water temporarily to facilitate stand establishment. Surface water drainage systems can accomplish this. The water disposal system should be designed to remove water during critical land clearing activities and stand planting. Bedding can be used in wet areas for a longer term solution to root growth inhibition due to soil saturation.

CASE STUDY

The property selected to demonstrate the uses of minor surface drainage by the private non-industrial landowner is a tract of approximately 1,813 hectares located in Long County, Georgia. The majority of the property is woodland with the exception of small ponds, cultivated fields and pastures.

The primary management objectives for the property are timber production and farming. Timber production is oriented toward pine timber ranging from pulpwood to sawtimber. Farming consists of row crops and cattle. The landowner desires to maximize and maintain a viable timber and agricultural asset that will provide periodic income and complement the other natural resources on the property as well. Table 1 is a summary of the major timber stands and land use types.

Major hardwood species include laurel oak (Quercus laurifolia), black cherry (Rubus serotina), black gum (Nyssa sylvatica), red maple (Acer rubrum), and sweet gum (Liquidambar styraciflua), as well as other scrub oak species. The pine stands are variable, however, common species include slash pine, loblolly pine, pond pine and longleaf pine (Pinus palustris).

Agricultural production will continue to be an integral part of the resource management plan for the owner. Farming will be diverse, with target crops dependent upon local markets, price, production costs, and other factors. New farm fields and pastures will be developed where soil conditions, drainage and logistics dictate.

The owner also intends to expand the available surface water on the property for the purpose of irrigation and wildlife enhancement. Approximately .5 hectare ponds will be excavated for every 80 to 120 hectares of area. The ponds will be constructed with shallow littoral zones for aquatic and wetland vegetation establishment.

FOREST MANAGEMENT MINOR DRAINAGE

An example of minor drainage used in a forestry application can be illustrated by a 56 hectare parcel that was clearcut by a previous owner in 1989. This property was sold to the current owner in 1991. The overstory was comprised of large loblolly pine mixed with water oak (Quercus nigra), red maple and sweet gum. The understory and midstory were made up of dense titi (Cyrilla racemiflora L.).

Soils are loamy and poorly drained. The are classified by the Soil Conservation Service (SCS) as Ellabelle loamy sand and Mascotte fine sand. Ellabelle loamy sand is a deep, very poorly drained soil. It occurs in depressions and drainageways. The subsoil extends to a depth greater than 2 meters and is loamy. The seasonal high water table occurs from the surface to .16 meters below the surface. Slopes are less than 2 percent. Permeability and

available water capacity are moderate (USDA 1992). This soil is considered hydric (USDA 1987).

The Mascotte fine sand is described by SCS (USDA,1992) as being a deep, poorly drained soil that occurs in low lying flats. The subsoil is loamy and found at a depth of .67 to 1 meter. The high water table is 0 to .33 meters deep. Permeability is moderate and available water capacity is low. Mascotte is not listed in the hydric soil list (USDA 1987).

A road with a .57 meter diameter drainage pipe is located up slope from the tract. There is a similar road and pipe on the downslope end. A shallow ditch approximately .75 meter deep was dug between these two pipes to move storm event runoff through the tract. The ditch sides were graded back to a very gradual rise to mimic the shape of a natural stream and minimize the need to return and maintain the drainage structure. Shallow lateral ditches of the same design were also placed to remove any standing water. The bottom width of the central ditch was approximately .75 meters at the upper end and 1.5 meters at the lower end. Beds were plowed perpendicular to the ditch to avoid trapping surface water. The bedding operation also was utilized to facilitate the breaking up of a dense titi root mat. This was critical to the survival of the loblolly pine which was planted on these beds with approximately a 2 by 3 meter spacing.

This area, because of the flat landscape and slow draining soils, typically would be saturated or under standing water through most of the winter months. The standing water would persist into the beginning of the growing season and in heavier storm events during the summer. The ditching and bedding configuration was designed to remove surface water that collects during seasonal rain events. Removal of the water is critical to the early survival of the pine and proper root development. Once the stand is established and transpiration rates return to near normal the removal of this surface water by draining would not be as critical. The low side slopes of the ditch are intended to provide for a continual shallow drainage that will not need further maintenance. It is also expected that erosion and vegetation will reduce the amount of water carried off site in the later stages of stand development The partial retention of water during the dry summer months would be advantageous. Additionally, this ditch profile was designed to facilitate access for fireplows in the event of a wildfire, since the tract is on a paved highway and susceptible to this danger.

AGRICULTURAL MINOR DRAINAGE

Another area of the property was identified as an illustration of minor drainage as it relates to agricultural and forestry applications. In this case an isolated wetland of loblolly pine and cypress (Taxodium distichum (L.) Rich.) was surrounded on three sides by fields and the rest by loblolly flat woods.

Storm events would often result in water collecting in the wetland. Especially heavy or prolonged rains would run off from the fields, and overflow the natural wetland boundary, saturating the edges of the field. This resulted in restricted use of the fields primarily because of machinery limitations. The landowner operates a highly mechanized farm operation and is dealing with a seasonal crop that makes it critical that he plant, cultivate and harvest within narrow windows of time. There also is a need for irrigation in these fields.

A ditch was constructed from the wetland, across the edge of the field, and into an irrigation pond. The ditch was approximately .6 meters deep where it entered the pine/cypress wetland jurisdictional edge. It shallowed to ground level within 10 meters. The effect of this drainage was to remove the surface water. However, soil saturation was unaffected. The timber on the shallower edges of the pond was cut, parts were bedded and loblolly pine replanted. The soil remains saturated, both seasonally and during heavy rain storms. The standing water is removed and stored in the irrigation pond for future use. The surface water removal has not substantially

changed this wetland which still exhibits all three wetland parameters; soils, hydrology, and vegetation.

CONCLUSIONS

Private, non-industrial forest farmers generally have a strong commitment to good stewardship of the natural resources under their control. Those landowners that have holdings in the lower coastal plain must deal with water management problems. There are vast acreages of land that are classified as temporarily or seasonally flooded pine-hardwood areas. Stand establishment in this sort of area has a much higher success rate if surface water can be removed during the first few years of development. These same landowners do not have the desire nor resources to drain bottomland hardwood stands for conversion to pine. Even the use of ditching for surface water is usually limited on these land holdings because of the costs. Site preparation techniques are usually less intensive than those employed by industrial ownerships.

As hardwood pulpwood values increase, non-industrial private landowners will begin to manage those areas that are more conducive to hardwood timber growth more aggressively. This pattern is consistent with silvicultural activities by this type of landowner who attempts to achieve maximum production with the very minimum cash outlay.

The non-industrial private landowner usually has multiple use objectives incorporated into this management plan. While his objective certainly is to get the best return for this investment in forestry operations, he is not concerned about squeezing the maximum fiber from each and every acre. There is no consideration for the needs of production that a paper mill requires.

The purpose of minor surface water drainage is to control water during certain critical periods of time in a timber rotation. If soil saturation can be reduced during periods when equipment is operating, such as harvest and site preparation, soil damage and sedimentation problems can be reduced. Seedlings will develop and thrive in wet areas if they have the opportunity to get a firm hold in the soil with early root development. This is best accomplished by providing the right mix of oxygen and water in the root zone. This activity is not designed to affect the long term water table level, but will help establish a valuable long term woodland habitat.

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Table 1 Land Use Types

Type	Age	Hectares	% of Total
Natural Pine	30-45	593	33
Planted Pine	1-16	633	35
Natural Hardwoods	40-50	53	3
Cut-over	-	237	13
Cultivated Fields	-	178	10
Pastures	-	113	6
Other	-	4.5	>1

"A Case Study on Bayou Marcus Livestock And Agricultural Company et al. vs. United States Environmental Protection Agency and United States Army Corps Of Engineers"

Prepared for:

U.S. Forest Service, Southern Region & U.S. Environmental Protection Agency, Region IV

"Water Management Forested Wetlands Workshop"

Prepared by:

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April 20, 1994

I. Introduction

This paper was prepared as a case study on "Bayou Livestock And Agricultural Company et al. vs. United States Environmental Protection Agency And United States Army Corps of Engineers" (Northern District Of Florida, Pensacola Division No: 88-30275).

II. Objectives

A. To provide a case study on Bayou Marcus
B. To offer perspectives of the federal expert
C. With the benefit of hindsight, to offer interpretations of the meaning and impact of the decision.

III. Background, Case Chronology

A. Location - north and west of Pensacola, Escambia County, Florida Due East Of Peridido Bay

B. Size of tract was approximately 400 acres in tract #1, approximately 472 acres. Tract #1 was the focus of the Bayou Marcus litigation.

C. Classification Of Wetland Type

1. USF&WS - Mosaic Of Forested, Scrub, some Persistent emergent)
2. Forestry: Cutover (seedtree) Pine TITI
3. HGM - of slope, depressions, riverine, fringe

D. Regulatory Context

1. Federal:
a. Section 10 of the Rivers and Harbors Act
b. Section 404 of the Clean Water Act
2. Florida State Wetland
3. No county or municipal jurisdiction

E. Hydrology

1. Some water level control by Perdido Bay
2. Significant slope (22 feet local relief)
3. Regular flooding from Bayou Marcus
4. Some stormwater input
5. Some wastewater treatment input from plant via Bayou Marcus

F. Soils

1. Fresh Water Swamp = hydric
2. Klej loamy sands = hydric on the Bayou Marcus Tract due to long term saturation during the growing season
3. Lakeland sands = non-hydric

4. Mixed Alluvial land = non-hydric/hydric mosaic - site specific keyed to microtopography
5. Not hydric soils on county lists

G. Forested Stand Characteristics

1. Dominants were Slash Pine - Titi
2. BA = 60-70 ft ac-1
3. Estimated 4,500 bf/ac
4. Average stocking density = 157 stems/acre
5. Average tree diameter = 9 inches
6. At 19999989 prices, estimated value = $81,500
7. Assuming higher stocking = (300 stems/acre) $155,755

H. Forestry Operations/Site History

1. Site initially logged between 1900-1930.
2. Prior to 1971 property used for turpentine collection
3. Some tree harvest between 1971 and 1974
4. No evidence of any tree farming or on-going silviculture between 1974 and 1985. No documentation by victor, previous owner of Florida State Forestry.
5. 1985 Purchase by Victor
6. Some cattle grazing in 1985...in addition,
a. Some plat plans developed
b. Forestry Opportunity consultations with Florida State Forester - However, no records were kept. Clearing began in 1985 "designed to prepare the land for tree farming".

7. Roads: The network of roads constructed on the property generally parallelled the major ditches on the site. Roads were evidently constructed from the sand and sand/muck soils that were sidecast from the ditches during excavations. Some culverts were in place, and more culvert pipes were scattered throughout the site. However, culverts that were installed were not adequate to allow unrestricted flow and circulation of surface on the site. There were for too few installed culverts, and those that were in place were not properly maintained. In several place, roads acted to dam or pool water.

8. Ditching: An extensive network of primary and secondary ditches was excavated throughout the site. These varied in depth and width, but generally averaged greater than 5 feet in depth and 20 feet from side to side. Running water was observed in most of the primary ditches and in many of the secondary or cross ditches. The overall effect of the ditch network was to change the flow and circulation of surface waters on the site, and thus the extent of reach of waters of the U.S. Some evidence that ditching was effective in drying the site was provided by the vigor of pine seedlings and saplings proximate to ditches. On sites near ditches where drawdown of the water table had occurred, pine seedlings and saplings were larger and showed a more rapid rate of growth. This was most likely due to the fact that pines near ditches were not subject to as much stress associated with life in saturated soils with low oxygen content.

9. Stand Entry: Entry to stands for logging operations was accomplished via the road network and temporary skid trails. Most of the skid trails, especially at the west end of the property were located on extremely wet sites and had been used when the ground was very wet. Evidence that machinery had become badly bogged down as provided by extensive and deep rutting. Most ruts were full of water. In several areas, temporary

mats had been constructed of down trees in attempts to reduce ground pressure from heavy equipment and to prevent bogging down on wet sites.

10. Volume of Timber Removed: Based on estimates derived from an inventory of pine stumps on the site, an average basal area of 60-70 ft2/ac was removed from the site. This would represent the basal area of timber that would grow on the site under relatively natural (ie., undrained) conditions.

11. Pine Regeneration: Based upon our reconnaissance inventory of pine regeneration on the site, an average of 157 stems/acre had become established naturally (ie., not planted). Most of this regeneration occurred after the site had been ditched, and evidently during an interval after active logging on the site had ceased. Pine regeneration favored microsites within the wetland that were slightly elevated above the average elevation of the ground surface. These slightly elevated sites occurred either naturally throughout the site (given the irregularity of the ground surface), or they had been inadvertently created by movement of heavy equipment over the site.

12. Slash Management: Throughout the site, non-merchantable down woody material had been either left in place where it had been felled (broadcast), or piled with bulldozers into individual piles or long piles (windrows). Piles and windrows contained much mineral soil and peat along with woody material. Evidently, piles and windrows had been constructed with bulldozers that were equipped with standard blades and not rakes, sites proximate to piles and windrows were badly rutted. Some attempts to burn broadcast slash, pile and windrows had met with modest to very poor success. This was most likely due to (a) the timing of the ignition of fires, (b) wind and weather conditions on the day of the burns, and (c) the amount of mineral soil and wet peat that had been incorporated into the slash piles and windrows during construction.

I. Regulatory Actions/Enforcement:

1. August 1, 1986 - Corps Issues Cease and Desist Order

2. Victor: reaction of Victor to C&D and AO's ignored, incredulous, somewhat confrontational.

3. Real objectives of Victor..neither.."Livestock" nor forestry....but development- converting site to poise it for development through use of the forestry exemption.

4. March 30, 1988 - EPA issued an Administrative Order mandating restoration of the property to its natural condition.

5. Plaintiffs immediately filed suite to challenge legality of US Army Corps Cease and Desist and EPA Administrative Orders.

J. Personnel/Staff involved in Case:

1. William Kruczynski - EPA
2. Don Hambrick - Corps
3. Rebecca Lloyd - DOJ expert
4. Lyndon Lee - DOJ expert
5. Wade Nutter - Expert for Victor
6. Florida State Forester

IV. Results Of Court Decision

A. Summary Judgement - Court concluded plaintiff cannot qualify for a silvicultural exemption. Judge used the following rationale:

1. "Plaintiffs could not show that their conduct was part of an on-going silviculture operation".

a. "Plaintiffs attempt to bridge the gap between 1974 and 1985 by arguing the slash pines had a 12-15 year growing cycle and therefore letting the tree grow was part of an on-going operation...is "novel but has no merit".

b. No evidence of planting, site prep, no records.

2. "It is apparent that plaintiffs' conduct was not part of an on-going operation but an effort to establish a tree farming enterprise on the property which did not previously exist".

a. "It is undisputed that the property had lain idle between 1974 - 1985 and "modifications to the hydrology regime were necessary to resume operations"....404 (f)(2) was triggered because the flow and circulation of the waters may be impaired or their reach reduced as a result of the requirement for ditches, roads, etc.

b. "Statue exempts operations in place when the CWA went into effect, but imposes a permit requirement for new or additional activity affecting waters of the U.S. (Avoyelles)....Thus, even if plaintiffs' theory satisfied the requirements of 1344(f)(1)(a), such operation was limited to selective harvesting of natural growth. Thus, plaintiffs activity from 1985 onward was an additional activity producing entirely new and substantial consequences for the hydrology of the wetlands and adjacent navigable waters".

3. Finally, Section 10 violation due to adjacency and direct discharge to the tidal waters of Perdido Bay.

B. Plaintiffs' had burden to show government action was arbitrary and capricious, an abuse of discretion or otherwise not in accordance with the law.

C. Government entitled to judgement on both the complaint and counterclaim.

D. Plaintiff dismissed with prejudice at plaintiff's cost and liability to government on the counterclaim for restoration of the wetlands in question and for civil penalties.

V. Interpretation

A. Correct Judgement

1. Clear case to show changes in extent of reach, flow and circulation.

2. However, everybody's nightmare because of interpretation given to facts outside of a determination on flow and circulation/change in extent of reach.

3. Since decision, generally co change in historic interpretations by Federal agencies...given guidance memos, workshops (two), by EPA Regions, etc.

a. Clearly not an "On-going, established" silvicultural operation
b. Not normal" silvicultural
c. Demonstrable "Change in extent of reach"

B. But - Intensity issue..and "affects" languate...judge took liberty with F(2) recapture language - meaning/ramifications of decision unclear.

C. However, Led To Issuance Of Land Clearing RGL 90-5 addressing mechanical clearing.

VI. Lessons Learned - Top Ten List

1. Recognize And Cross Reference To HGM Types

1. Stress need for site specific and hydrogeomorphic specific judgement on what is minor drainage.

2. Stress importance of reference.

3. In Bayou Marcus, the case was clear, given the size of the ditches, Mr. Victor's intents for land use (conversion, not forestry) and the fact that ditches were connected into a systematic network to move water to Escambia Bay (west) end of site.

B. Always Check & Double-Check:

1. Normal silviculture
2. On-going and established operations
3. Use of BMP's
4. Change in extent of reach, patterns of flow or circulation - leading to conversion of use

C. State Foresters failed to do their job correctly. They should have been held more responsible for advice for clearing, BMPs, lack of record keeping, etc. Synthesis: states need training on 404, f1 & f2.

D. No mater what size of forestry operation, don't fail to keep records. Have a silvicultural plan, even if it specifies relatively long rotations. Keep documentation current.

E. Communication: CWA 404 (f) 1&2) interpretations are not easily accomplished with the lay public.

F. To companies, agencies and landowners...

1. Hire competent foresters to develop and document silvicultural plans. Keep them current.

2. Further, make sure they understand the laws...

3. As a large or small private landowner, make sure your consultants are held accountable for their advice...(even if they work for the state).

G. Court is no place to manage land...its always a gamble and sometimes the judge can and will offer opinions or interpretations that depart from standard or historic interpretations.

H. Don't mistake what you're doing to have only local significance. For example, results of this workshop will provide EPA Headquarters guidance and will have application throughout the U.S.

VII. Literature Cited

Avoyelles

Bayou Marcus decision

Bayou Marcus article

Escambia County soil survey

HGM

QUESTION AND ANSWER SESSION, AFTER EACH WORKSHOP SESSION

SOILS SESSION:

DeWayne Williams
Dr. Thomas Fox
Dr. Michael Aust
Jim Robinson
Dr. Robert Shaffer
Jack Hill

1. Question regarding the Lockaby study - Harvesting decreased the water table, why?

Speculation that a dark surface (organic soils) and decreased transpiration is offset by an increase in evaporation in phosphorus deficient sites. In the second year the water table was normal. There are many differences between sites, can't make sweeping generalizations.

Logging was also shown to decrease water levels in Florida cypress domes and produced very small changes in the water table on very poorly drained soils in South Carolina. Transpiration from trees effectively lowers the water table because deep rooted trees are able to remove water from portions of the soil too deep for evaporation to be effective. However, transpiration requires more energy per unit of water than evaporation (energy is lost to resistance at the root-soil interface, within the conductive tissue, to lift water to the leaves, and across the stomates). If the soil is saturated, or there is standing water, cutting trees removes these resistances and the available energy will evaporate more water. So cutting trees will increase water levels only when the pre-logging water tables are below the level where soils dry by evaporation alone, probably 5 to 10 cm.

2. What is the threshold point between the decision of whether to bed or not?

Depends on the biological situation of a given forest. The growth response to bedding may be due to a combination of factors, including: 1) improved soil aeration; 2) a doubling of the amount of topsoil available for seedlings and 3) providing competition control. Even on drier soils, there is a growth response to bedding due to 2) and 3). On wet sites that are flooded for 3 - 4 months per year, bedding alone is not enough. Survival can be poor and growth inadequate.

Bedding is indicated on poorly and very poorly drained sites, where better seedling survival results from better root aeration and to a lesser degree, slight increases in fertility. Sometimes additional fertilization is necessary on better drained sites, may see a response to bedding due to competition control, bedding mechanically reduces weeds. But this response is short-term and not economical, and on erosive soils it may have long-term negative impacts.

3. What are the different, including negative, consequences to water management (use of flashboard risers)?

Plantations change the structure of the ecosystem. This is often viewed as having a negative impact on biological diversity, including fauna. However, there is structural diversity, and wildlife habitat, within a pine plantation. Water management structures involve a series of tradeoffs, the question to be asked is what is the most important for the landowner? Little that we do within wetlands has all positive or negative consequences.

4. Have State regulatory agencies begun to regulate the discharge outflows from flashboard risers?

Not yet, although it may be coming. There is little public push for regulating this at this time.

5. What questions should be asked with regards to water management?

Alternative silvicultural systems, not just pine plantations, can have detrimental environmental effects with regards to manipulation of the water table. Key question - what is the objective of your management? Will the hydrologic management objectives be achieved? Is it still a natural system, does it mimic natural hydrology?

6. On what sites, or what situations, is rutting related to water quality?

Minimal slopes involved (<3%) within the studies mentioned, soil texture and permeability were key factors. Flood plain areas are sediment deposition areas, skidded areas trapped more sediment that the control area. Unless skidding occurs in surface water (flowing), or within well-defined channels, rutting in flood plain areas is more related to on-site impacts than off-site impacts. In the "Blackwater study", people looked at herpefauna relationships, perennial pools formed that aided herpefauna in breeding and improved habitat resulted from the disturbance.

7. Are soil surveys reinterpreted on a regular basis?

The SCS is continually working on re-interpretations, the USFS and others are cooperators. Improved interpretations are in the works. Due to publishing constraints, even the latest soil survey data is a little old when published. Technical guides available in each county are the best information to use.

8. The EPA deals with a lot of not very sophisticated silvicultural/forestry systems, how do we deal with deficiencies of information? When harvesting pine and regenerating pines?

The lack of good information is a serious problem. Most timber companies have gone to the expense to map their own soils instead of relying on SCS data, a lack of technical soils information is a real problem. Expertise needed to evaluate soils on site, it is an expensive proposition. Published information is not readily available to small landowners, and oftentimes they are unaware of existing information. An extension push is needed to get the information out to those who need it. The Stewardship Program is a good multiagency example of developing local implementation regulations. National guidelines have their limitations. Local input is needed.

9. How do State forestry personnel get information to the public?

Often times the information is for site preparation and cost share assistance. The information is shared via one-on-one personal communications, aerial photos, soil surveys, and by other resource professionals.

Often times state personnel get to field sites during, or after, harvesting operations.

10. Observation - A lot of regulations are now being developed at the local level. Timber mills that procure wood have a responsibility to get good soils information to those who raise the timber resource. But they can only go so far due to antitrust regulations.

11. Comment - Within the southeast, only the Federally listed BMPs are mandatory in wetlands. They primarily involve road work in wetlands. Industry is working with private landowners to make sure they comply with state BMPs. State forestry personnel try to ensure that landowners are aware of the legal issues.

12. Regarding discharges from water management structures, what is the quality of the discharge versus natural water conditions?

In general, water quality is good coming from structures. Water quality can actually be of a higher quality coming from structures.

13. Comment - With BMPs in place, water quality is good leaving harvested sites.

14. Not all hydric soils are in wetlands, is that true in natural conditions?

The Rains and Leon series are part hydric and part not hydric. Some soils that are not mapped as hydric can be reclassified as hydric based on field interpretations made. Vegetation has five categories of classification, soils only have two categories, is it hydric or not? The need for field verified hydric soils was stressed. Is a wetland involved or not?

15. Comment - Forested wetlands have the least detailed soils maps available. Agricultural lands have been mapped much more intensively. There is much more soils variation in forested sites versus agricultural lands. Soils maps alone should not be used to determine if an area is a wetland. Field verification alone of hydric soils does not necessarily make a wetland, all three factors are needed (soils, vegetation, and hydrology).

16. Vegetation is not very closely correlated with soils, wetlands vegetation may not be correlated well with the site. Hydric soils can indicate wetlands, but vegetation alone can be very misleading. "Ronnie Best" data - published lists of indicator species are not very helpful for indicating hydrophytic vegetation. A local approach is needed. A flatwoods system is not applicable elsewhere.

17. Our belief that concentrating logging damage to a small area is not always best was challenged, dispersing logging damage may be preferred depending on the site. The answer depends on site conditions. An example was given regarding coarse soil material over clay, as long as skidders don't cut down to the clay layer, subsurface drainage is not disrupted. If you do cut down to the clay layer, an operator would be better off concentrating the logging traffic.

18. Comment - Hydraulic conductivity measurements done in the field and in the laboratory came out the same. Disturbed sites don't have the same level of macro pores as undisturbed soil.

19. Are red river systems, or any other river system, more sensitive than other systems?

River systems are obviously different, can't say one system is more sensitive than another regarding all functions.

- Organic areas have higher potential for impacts.

20. Better information is needed from states to non-industrial private landowners, how can the information transfer process be expedited?

The SCS is making progress to digitize soils information. Pressure needed from outside to expedite the process. Florida is the leading state in this respect, state funding was used. 10 - 20 year time bracket envisioned for widespread availability of GIS soils databases.

21. Water management always needs an active system with adjustable risers. A system can be planned with ditch depths and culvert inlets set at elevations which will provide drainage at high water tables following logging and site preparation but not function as the new stand lowers the water table. Such a drainage system could be installed at the time of harvest planning. Such a plan would also require that regulators understand that such a system may not be manipulated for 30 years but still constitutes active water management. Ditch construction and maintenance have the greatest water quality impact of pine plantation management. Systems that minimize this activity should be encouraged.

Water management structures are needed in the south versus simply plugging ditches. Increasing management on water structures increases costs. Water management is desirable, high costs and good record keeping are important factors to consider.

22. When statements are made about the conversion of hardwood forests in the flatwoods to pines, land use history is often overlooked. How important is land use history of an industrial land base?

A historical perspective is needed, all forest systems in the southeast are disturbed to some degree. We have misconceptions what these stands looked like 100 years ago. The historical pine component is often times underestimated. An example was given of the girdling of loblolly pine years ago to favor slash pine since they didn't give resin for turpentine. When turpentine production ceased, the forests were harvested, again removing a pine component. Pine removal from bottom land systems has been great. Fire suppression released hardwood midstories and has increased the hardwood component of stands. Our perception of pure hardwood stands within all bottom lands is probably incorrect. Pines can compete quite effectively with the hardwoods.

"Pristine" areas, are often times not pristine, areas have been harvested many times. Signs of pull-boat logging today is but one example. There is a lot of history on any given wetlands site. Some of our hydric soils can be "relic" features of past disturbances, developed by climate and soil forming factors. Redoximorphic features indicate where past water tables were, not indicative of today's levels. By and large hydric soils give us a fair history of land uses, but not all hydric soils are wetlands.

HYDROLOGY/MODELING SESSION:

Dr. Mark Brinson
Dr. Wade Nutter
Dr. Wayne Skaggs

Dr. Carl Trettin
Dr. Tim Adams
Dr. Warren Harper
John Dorney
Donald Woodward

1. What is a reasonable method of determining evapotranspiration (ET)?

We would like to use "Penman and Montieth" model, but difficult to use; can use surrogates or can take shortcuts; need to do sensitivity analysis. Can use a daily constant value for ET/month. Can use any method that you have the data to drive a given model.

2. Three conditions to water management in forested wetlands were stated, are there triggers for wildlife or other items? -or said another way- to what extent can habitat changes take place under the umbrella of water management in forested wetlands?

If you change the three stated conditions, then you fall out of the framework of the model. Wildlife questions are functions within the given hydrogeomorphic (HGM) class. Can have a natural background of habitat change for sites that burn frequently. Silvicultural practices can change the above-ground biomass.

3. Need to understand the physical attributes of a wetland first - how difficult is it to find "reference" watersheds?

Reference watersheds can vary from "pristine" to hurricane damaged areas. Somewhere in the middle is the ideal reference watershed. Any forested wetland that has undergone an assessment can be a reference watershed. Need to shoot for a sustainable condition for a watershed. Silvicultural activities done on a watershed do not exclude it from being a reference watershed. To determine reference watersheds you need to look at what you would wish to have and what you have at hand, need to select sites as "end members".

4. Reference W.Nutter's third test regarding conversion to non-wetlands. How difficult is it to use drainmod or some other model?

Models developed for a certain type of land are not that difficult to implement. The models are to be utilized only within their design constraints. For example - relatively flat sites, rainfall driven systems, and no ground water inputs.

5. When are models appropriate to use?

Models should not be used by people without adequate training in hydrologic modeling. Models can help us see how ecosystem parts interact. Need for caution when using the models. Sensitivity analysis needs to be done, especially by trained personnel. Models are expensive to develop in themselves, but cheaper than subjective/off-the-cuff analyses. Models can help us bracket risk when making silvicultural decisions.

6. Comment - Drainmod will be made more easily workable in the future considering the increasing availability of computer databases.

7. With respect to loss of soil carbon as a result of forest drainage systems, which is the greater problem, loss through the atmosphere or through the water?

We do not have information to assess the partitioning of carbon loss through gaseous and aqueous pathways. This needs to be determined to assess energy inputs to streams and greenhouse gas emissions. We do know however that drainage reduces methane flux because it is oxidized in the aerobic portion of the soil.

8. What is the source of data for cumulative analysis with regards to silvicultural situations?

This is a difficult question to answer. There is no repository of data. Cumulative assessments require integrated approaches to data acquisition and analysis. EPA's Chesapeake Bay Program is mentioned as an example of a comprehensive look at solving this difficult problem. The ACE basin study in SC is another relevant example.

9. Is the HGM methodology the correct way to go?

The use of intuitive indicators can lead you astray in your analysis. Need to pull back to a regional scale. Certain indicators may not be good to use in places, in that case different indicators need to be used. Need to develop a comprehensive list of indicators for a give function.

10. Wetlands functions are very different, can they be summed?

As a general rule, don't take indicators any further than they were designed to be used. Look at them on a function by function basis. Don't compare wetlands functions between different wetlands systems (riverine, etc.). Don't try to sum wetlands functions to compare among different wetland systems. The scaling and sizing of functions is different, emphasize reference wetlands. Scaling and weighing needed, within reference wetlands and within the project area. What represents a significant change? Is the policy 25% change, 50%, etc. Look for a consistent way of looking at ecosystem functions. Viewing wetlands with respect to the HGM system is not simpler than available alternatives. Can be difficult to quantify functions. Some functions have to be quantified, that can be difficult to do. Avoid extrapolating beyond available data.

11. How to estimate carbon loss from ditching?

Carbon loss can be simply measured as the change in soil carbon pools over a period of time. A preferred approach would be to measure carbon flux in soil gas and water, in addition to assessing soil carbon pool size.

12. Comment - Wetland functions change with stand development.

13. Wetland drainage may decrease ET, but usually increases tree productivity, explain?

In ground water discharge wetlands that have the water table at or near the surface during the growing season, ET is typically at the potential rate. Under natural conditions where the water table is below 30 - 40 cm actual ET rates are less than the potential, primarily because of reduced evaporative losses and transpiration by shrub and herbaceous vegetation. Drainage typically lowers the water table 20 - 50 cm.

by transferring water that would have discharged to the surface into the ditch system. In this manner ET can be reduced. In contrast on sites that naturally experience a fluctuating water table, the overall change in ET as a result of drainage may be negligible.

14. Is a chronological sequence envisioned for the HGM approach?

It would be an absolute necessity. Target references must be compared to your target area, including a time dimension.

15. How do you get the person on-the-ground to use the HGM or drainlob model?

Training needed of technical people. Technology transfer of key components of models needed. Decision making is now a more hierarchical level and it is a complex task. HGM or drainmob would be more readily acceptable under a complex decision making scenario. May need to use drainmob if the values are within it's design parameters. Regulations may be more of a constraint than the functions. Production objectives must be addressed.

16. Minor drainage takes a long time to show up. Can a model be a part of a larger model in forest stand development or for forest planning purposes?

This has been done with crops to predict yields pretty well. Links hydrologic models with cumulative impacts downstream. Hydrologic modeling has it's limits, can't do as good a job with water quality within streams.

SILVICULTURAL APPLICATIONS,

Dr. Paul Lilly
Dr. Robert Kellison
Dr. Bill McKee
Dr. Bryce Stokes
Dr. Robert Rummer
Stan Adams
Dr. John Stanturf
George Henderson

1. A comeback in planting upland hardwoods for fiber production is occurring, there is a serious problem with quality hardwood production. How can we change these patterns? How do you harvest these quality hardwood sites without drainage?

Stumpage prices are going up, therefore it may become economically feasible for folks to grow and produce quality timber. R.Kellison does not look to see much quality hardwood timber harvested from the National Forests in the future, industry must look to the private sector for quality hardwood timber. It must be economically attractive to grow quality hardwoods. Few timber companies are intentionally growing quality hardwoods today.

Minor drainage of an unaltered system is almost always detrimental to bottomland hardwoods, species composition is degraded when water is trapped on the site, and invasive species often result when minor

drainage occurs. Without forest drainage, we must look to improved harvesting systems and equipment. Must look at growing and harvesting access. Look more to the growing of the trees with regard to not using minor drainage. A lot more can be done with conventional logging equipment without going to exotic equipment.

2. Comments - Wide tire skidders (68") do give good results in bottomland harvesting. Poor experience with cable systems within bottom land hardwood systems, not effective greater than 1/4 mi. in distance. Can there be more collaboration between industry and the personnel at B.Stokes research work unit?

Dr. Stokes agreed completely with opening comments. Cable systems are not necessarily THE answer, rather look at them as an alternative. Dr. Stokes research work unit does work closely with industry. Lack of funding has been an issue. Dr. Stokes research work unit doesn't work exclusively with harvesting/access issues.

3. What upland pine sites are envisioned for hardwood plantations?

Includes a range of the best pine sites, including those on river bottom terraces. Early hardwood plantations were established in red river bottoms. A lot of the hardwood plantations established in the 1970s and 1980s were on the first and second bottoms (floodplains). Those stands often did not perform to expectation because of inability to silviculturally treat them at the appropriate time, and they were inaccessible for harvesting because of high water and saturated soils when needed. New hardwood plantation tests are being established on the best pine lands out of the floodplain. These intensively managed plantations will require monitoring for soil erosion and chemical runoff.

4. The effects of past land use are very important. We need to consider regional effects of forest drainage. What would be the productivity of lower coastal pine sites without the ability to use forest drainage?

Regionally I don't see us bringing many new areas into pine production. The biggest limitation to planting on saturated or flooded soils is seedling survival and then productivity would suffer. In eastern NC we have influenced the hydrology over entire regions with past drainage practices, including: highways, snagging, etc. Local areas that were not specifically drained are generally better drained today due to all the regional drainage. The blocking effects of drainage can be devastating.

5. There exists the need to separate internal drainage factors, under what specific conditions would you expect minor drainage to increase loblolly pine productivity?

Forest drainage has the biggest effect in the establishment stage. Forest drainage is less significant later in stand development, except for very wet sites. Forest drainage is mostly a pine establishment/regeneration issue. Not a significant factor for long-term stand growth, it is a significant factor in initial stand stocking. Forest drainage is a very important economic tool, it can be a make or break factor.

6. Comments - Loblolly pine is increasing in the Hell Hole Bay area. Comments regarding tupelo/black gum stands -- Subsidence is associated with drained headwater swamps, and there is speculation that the same kind of subsidence had occurred on the Santee River where the water was diverted to the Cooper River in the 1930s. The encroachment of loblolly pine and red maple into the blackgum swamps is thought to be a result of this alteration. A divergent opinion is that swamp tupelo develops water roots that form

hummocks and accumulate organic matter that facilitates the establishment of pine and increase the area for loblolly pine. Pine invasion is not necessarily dependent on hydrologic modifications. Loblolly pine develops on hummocks in non-alluvial areas and can dominate a site. The accumulation of organic matter dries out non-alluvial headwater swamps in the absence of fire. Fire will decrease the organic matter.

7. Comment - Regarding establishment of hardwood plantations on upland sites (out of the floodplain), there will be more opportunities for non-point source pollution to occur on upland versus bottom land sites.

In response, the opportunity for nonpoint source pollution is probably greater on upland versus bottomland sites, but the fact remains that hardwood plantations will be increasingly found on the best upland sites. The reason is that timber is often unavailable during periods of inclement weather on bottomland sites, and those sites will be less available for intensive forestry because of corridor preservation.

8. Is technology available to improve loblolly sites without forest drainage?

Looking for loblolly genotypes more tolerant to flooding, no big differences have been found to date, although this has great potential. Phosphorous application is very economical and yields good results, prices range from $30 -40/ac. Bedding can be very expensive as compared to fertilization. Application of phosphorous within tube seedlings is a possibility. Look to pond pine for certain sites. Look to wet site loblolly also. Potential exists for improved technology.

9. How would hardwood plantations be established?

The sites would be intensively site prepared for use of the best genetic material, including the use of vegetative propagation. The use of herbicides and fertilizers, and perhaps irrigation, will be common practices. Monitoring for soil contaminants and erosion will be an integral part of the system.

10. A bench marking spectrum to evaluate forest drainage is envisioned, how do we rationalize this with regard to the long history of drainage in eastern NC?

No "pristine" sites available for bench marking. Scale within the present condition with the best available professional decision making. Look at those class of wetlands in the area in question. The system doesn't preclude the use of historic data. The difficult part is to identify the target reference. What the public will sustain is another side of the equation.

11. Have the impacts of sled harvesting systems been examined? Harvest road planning?

Have not done any research studies in this area. Based on observations, it is best to get the wood off the ground, either using tired vehicles or some other system. Sledding may be a good choice. Has not been looked at it from an impacts to hydrology standpoint.

Planning of forest roads is highly variable, it ranges from engineered roads to very minimal roads left up to contractors to design and build. Highly designed roads are the exception rather than the rule. GIS systems lend themselves well to forest road planning.

12. Comment - In SC there is a sledding operator that uses a high-float feller buncher and high-float loader, minimal ground disturbance results. This operation uses all track machines in the harvesting

operation. Then a cable system brings the sled out to the road. Impacts do occur in high water table areas. Can be very minimal damage to the soil.

13. Has anyone looked at a permanent "ski-slope-type" harvesting operations?

Not too much, but the costs involved would be too expensive for a given site.

14. We've heard that many of the impacts of harvesting on wet sites can be avoided, or at least minimized, by modifying existing equipment and techniques. Where then should the research effort be directed? Should we continue to incrementally modify existing ground-based equipment, or will these new technologies yield a quantum leap forward? What's the economic cost-to-benefit picture? Are these new technologies going to be very expensive but only yield a modest environmental improvement?

A lot of new technology and new techniques have been employed to protect the environment, especially with regards to road building and harvesting systems. We are still seeking solutions to harvesting problems. Rubber tired machines with 68" tires are part of the solution on wetland sites, are limited on some soils and moisture regimes. Not all problems can be solved with rubber tired machines. Incremental gains are being pursued in harvesting systems. When will we be willing to spend more to protect forest values, how much are we willing to spend? New concepts that may appear to be unfeasible today may be feasible in the future due to environmental constraints and higher stumpage rates. An assumption is that ruts are bad, is that always true? What damage levels are acceptable? Are we trying to solve problems that may not be problems? What are our limits? What are the values we are trying to protect.

15. What level of damage results in loss of productivity?

With regard to bottom land hardwoods, can we treat these areas fairly rough and will they bounce back well? Adverse impacts to water is the most critical issue. The lower the quality of pine sites, the more they can be damaged through harvesting impacts. Low fertility areas with poor hydrology can be negatively impacted. Only anecdotal evidence available at this time. Damage from old pull boat logging does not appear to be great today, considering the impacts then were very great. Harshly treated sites of yesterday appear fairly well/productive today.

16. Comment - Soil organisms are crucial to recovery of damaged soils. Crawfish and other soil boring fauna can help reestablish local hydrology.

17. Comment - Wetlands functions, has it been lost or is it capable of returning to its original condition, as compared to a reference condition.

18. Comment - Clear-cutting is the best method for regenerating bottomland hardwoods, but "political" constraints will rule against that practice on selected sites. The alternative is to use properly implemented harvesting practices such as shelterwood and group selection to obtain the desired reproduction.

PRACTICAL APPLICATIONS AND USES

Bob Fledderman
Bart Sabine
Dr. Lyndon Lee

Dr. Donal Hook
Jim Allen
Dr. J.W.Gilliam

1. Minor drainage is needed mostly for harvesting and planting, trying to remove surface water. Some flash board risers have been abandoned on industrial lands. Why not leave some type of water control structure there all the time? Perception is that a site may be changed from a wetland to an upland. Forest industry may be amenable to installing flash board risers for water management. The installation of flash board risers can avoid the perception that wetlands are being converted to uplands. The problem is determining how many risers would be necessary. One per lateral? - an expensive proposition. One per "X" ft. in elevation? Water control structures may not be necessary for every prescriptive drainage situation.

Two kinds of drainage systems - very sparse, surface systems versus pattern drainage systems that control subsurface drainage. Density of drainage ditches is important, the soils they are in are critical, mineral versus organic soils. Have the water source vectors been changed and have the wetlands conditions been changed?

2. What is the maintenance required with a pattern drainage system, including routine maintenance?

Primary ditches are generally maintained every 10 - 15 years, secondary ditches once per rotation. Some maintenance is being done to ensure that ditches never become clogged and dysfunctional. Old ditches can be maintained, construction of new ditches, or the reconstruction of dysfunctional ditches, can be questionable. Maintenance is done during the dry season. Herbicides are used for weed control and some site preparation. Herbicide BMPs are used, for example, buffers are established adjacent to water bodies, limits on acceptable wind speed and directions, and ensuring that label directions are always followed. Herbicides that are used for control of weeds in ditches are compatible with aquatic use.

Comments regarding water in drainage systems:
1. Excellent source of water for fire fighting
2. Slows water leaving a tract and sediments dropped.
3. Water in ditches retards weedy growth.
4. Offers excellent open water wildlife habitat.
5. With regards to tree growth, after stand establishment the laterals have little to no effect on stand development.
6. At times water is put back into dried out organic soils where drainage has done too good a job.

3. What are muck swamps?

Blackwater swamps with a deep organic layer underneath.

4. Are there opportunities to take advantage of drainage to create valuable wildlife habitat? Leave trees along edges of drainage ditches, meander ditches, etc.

Industry may be reluctant to do that because of the regulatory environment, creativity may be limited due to regulatory controls. Difficult to value "other" stand values, timber is easy to value, wildlife is much more difficult, better to use ecosystem functions. Owners of large forested tracts have other values such

as aesthetics, wildlife, and recreation to consider. B.Sabine has planted and curved drainage ditches for non-industrial private landowners (NIPLs). COE has a concern in towns with maintenance of ditches, may lead to destruction of some tree plantings. Drainage systems depend on your goals, remove water for stand establishment, after that slow the water down and try to retain water on site. No interest in ditch maintenance under some circumstances. Significant and temporary ditches may be classified as minor drainage. Temporary is a key component.

5. Comments - Water quality coming off of pine plantations is as good as any in an area, much better than agricultural runoff. Potential to manage water to improve water coming off of agricultural lands passing through forested lands. Forests acting as bio-filters. Spread the water out and slow it down, it costs dollars to be creative.

6. Comments - Landowners have a variety of options for solving silvicultural problems. They can choose the objective that has multiple benefits, a meandering drainage ditch for example. There are numerous silvicultural options to meet our objectives. Outcome based planning versus regulation. Need to stay open to new solutions to silvicultural problems. NIPLs want to receive the dollar value of their timber and meet their other needs also.

7. Comments - Keep the blockage of streams from killing bottom land timber. To what extent is flooding an equal problem?

What are we trying to achieve? What is consistent with our goals. Judge deviations of the functions from the target state. Consistent or inconsistent with target reference wetlands.

9. How do you get HGM system to work?

Drainage is but one consideration in managing a timber stand. How do you sort out changes related to function, related to drainage versus other management activities? How to assess functions with regards to drainage only?

Need to have homogeneous wetland types. Depressional situation, flat woods with drainage. Goal is to effect short-term drainage. Need to combine the functions into an index.

Need to sustain the target reference during a rotation. Surface water storage could be a target reference. Some of the functions being considered are: short- and long-term storage of water, water velocity reduction, and productivity. Need to get away from "good" and "bad" minor drainage. The soils data can be used to determine site index as an indicator. Site index is a surrogate for primary site productivity. It is possible to delete one function of a wetland for one part of a rotation and still meet the target reference.

10. Two questions: What is an appropriate wetlands value? What functions need to be quantified?

A consistent framework is needed to compare sites. Numbers will be needed, such as scaling and weighting, consistency will be needed. Still working on developing indexes. A consistent way of developing functions is needed in a reference system. Thresholds will be needed to determine what are and what aren't acceptable functions to use. Values can be regulated, functions can't.

11. With regards to an index of function for wildlife habitat structure, how do you differentiate drainage

effects from other effects?

When target wetlands are assessed, how do you sort out all the associated management that goes on? Activities outside the range of the drainage? Case and field studies will be needed to perfect the HGN model.

12. Current regulatory programs stop short of quantifying functions. The HGM model will have a subjective component. This will make it difficult to summarize the effects of changes in function.

We use indicators all the time, need to develop what is known and what information is lacking in developing indices. HGM has evolved from a binary system to a sliding scale, a third level is envisioned. Data will be needed for sites, therefore a sliding scale is needed.

13. Will this model be predictive?

Envision that the model will be used as an assessment model of planning. The features of a site will be needed to make a judgment regarding a site.

14. How will the model be applied, to drainage only or to all activities on wetlands?

Current methods available aren't adequate. COE says they aren't adequate. Mitigation, creation, or restoration of wetlands is needed, functions need to identified first, the HGM model is the next step beyond the COE project. There will be numerous indices, some will go up and others down, ten indices to be used. Reference systems are very important. Compare positive aspects to the negative, remembering that no change has value also.

Nitrogen and phosphorus outflows could be worked in as indices, need to look at all the functions and not just one. M.Brinson's COE group is working on completing the model by June, 1994. It will not be a cookbook. Need to apply the overall knowledge of wetlands to this model. Forest industry is in the best position to do this.

15. Can the HGM model be used to address cumulative impacts over a landscape regarding one function?

Difficult to look at one function on a stand-alone basis, need to look at the aggregate. The system is not designed to look at cumulative effects. The Edisto River basin study will use indicators to lead to cumulative effects, a GIS system to be utilized.

Short-term impacts to managed wetlands need to be looked at over time, wetland systems are very resilient in general. Forest drainage isn't that big an issue during a rotation. What temporal scale will be used? Mid-rotation access is needed for fire suppression and other management needs. Forest drainage is needed at the beginning and at the end of rotations, is it needed in the middle of a rotation? Thinnings and other mid-rotation entries are needed. Over a large forest area that is drained, different parts will be entered on a regular basis. The intensity of drainage is the issue, drainage will always be needed on some sites.

16. Comment - It appears that the actual implementation of the HGM model would be very difficult to implement in the field.
It is obvious major drainage would obviously fall out, obvious minor drainage would fall out, the test

would be used with borderline situations. Time and field testing will be needed for different regions.

GENERAL PANEL SESSION OF FEDERAL EMPLOYEES

DeWayne Williams, SCS
Linda Gantt, FWS
Steve Gilbert, FWS
Jack Hill, USFS
David Crosby, COE
Tom Welborn, EPA
Frank Green, GA Forestry Commission
Fred White, NC Forest Service

1. Are people using the SCS developed drainage guides, with regards to engineering considerations? Limitations? Who is using them? Are they a starting point to be built on?

Guides have minimum drainage depths by soil, but not maximum depths. Not very applicable for removal of surface water, used primarily for subsurface drainage. Guides written for agricultural use, not designed for forestry use. The minimum and maximum depths for drainage guides in Georgia had the same minimum and maximum depths for all 118 soil series.
The guides were developed in 1930's and 40's in each state, developed for cropped soils, and laid out the best practices primarily based on the best professional judgment. The technology has developed much beyond the drainage guides. The guides are not based on science. The spacing guides are based on a rainfall event in 24 hours to protect agricultural crops, 50% chance rainfall event removal. The guides are not very applicable for wetlands applications. South Carolina guides have no maximum depth for any forest soil.

The guides were developed. to remove subsurface water. Did not consider over-drainage at the time, that is why maximum depths are not given. Depth is not a critical factor, the spacing between ditches is more critical.

Two types of drainage systems - surface & subsurface. If the guides were developed for surface drainage, then the guides would be a good starting point for wetlands use. If beds are used that are not tied into the ditches, you have more surface drainage, do you have a surface or a subsurface drainage system?

2. Can a classification system and BMPs be developed for application in these systems, such as the following?

A proposal may look as follows; types, or groups, of drainage, four classes:

1. Bottomlands (riverine) - branches, streams, creeks, and rivers with hardwood sites. Water management in these areas is aimed at maintenance of natural water levels and short-term drainage or restoration of natural water levels.

2. Swamps and ponds (depressional) - Very wet hardwood sites. No drainage or very limited drainage. Long-term removal of water will result in significant hydrological impacts.

3. Coastal Plain Bays (depressional) - Drainage is impeded. Sites tend to have pine, hardwoods, and/or scrub shrub. Drainage has potential to change hydrology and varies with type of soil, which varies from mineral to peat soils. Some sites have been drained and planted to pine which requires bedding.

4. Wet Flats (slope) - Typically pine sites, but sometimes mixed hardwoods. Drainage is done to improve growth and to allow harvest of sites. Water control structures can be used to maintain hydrology. Bedding and site preparation on these sites is done regenerate pine stands.

Can we come up with a guide/BMPs for each of these 4 systems?

Drainage specifically intended to de-water a site to allow for harvesting would apply to all 4 categories. Need to recognize that many of these wetlands are transitory and species composition can change over time, can be due to sediment deposition. What can be a drainage system initially may not be in a few years. Suggested to incorporate a reference system in each of the 4 classes. Work inside a reference system, what is typical and not typical? Compare planned works against the planned BMPs. Recognize BMPs, stratify them into a reference system. Stratification is desirable, how would the BMPs be developed? Best to be developed at the state level, perhaps by the state forestry agency.

A multi-agency approach to the development of drainage BMPs would be best. Sonoco did this in SC with drainage. Mentioned the need to develop standards and guidelines as the USFS has done in forest plans. Best if BMPs developed by ecoregion or province.

In South Carolina SCS personnel tend to work primarily on agricultural lands. State forestry agencies and industry have worked together in the past on BMP development. If you stay within states, the state conservationists can provide assistance. SCS workload has been more single purpose because of the Farm Bill. The SCS is willing to work in the area of wetlands BMP development. In North Carolina, the SCS has also been very cooperative in this area of BMP development.

Look at wetlands classes and categories, look at drainage as a tool to accomplish objectives. Should stand yield/quality issues be included also? HGM could come in after the above four-part outline was developed.

What influence does drainage have on a "target watershed? Restoration and mitigation questions are complicated/more difficult activities to work on, one activity would be easier to look at.

What are the impacts of drainage on any given activity? Can the target reference condition be sustained? In the impact assessment stage use HGM as a design template, the framework is still being developed.

3. The CWA was designed to maintain the integrity of our nations water. The FWS is moving to an ecosystem-conservation orientation. The FWS is moving from a single species viewpoint to an ecosystem standpoint. Think about how we can work as a team to work on ecosystem restoration activities. Need to discuss research needs regarding the "conversion" of hardwood stands to pine stands and their wildlife impacts. What are the impacts of hooking into existing drainage systems?

4. The FWS doesn't have any real concerns with removing surface water for harvesting operations. Have concerns with drainage to change site uses. Concerned with changes from a structured hardwood habitat to a pine monoculture habitat. Habitat evaluation procedures are a tool to look at habitat changes.

Concerned with wildlife diversity in pine plantations.

5. FWS is concerned with changes in species composition, alterations of inflows to estuaries, and neotropical migratory birds. BMPs that deal with wildlife and wildlife habitat are pretty much up-to-date. Edisto basin watershed mentioned as a good example of an interdisciplinary approach. Applications of minor drainage in forestry activities from a FWS perspective, if a long-term change in habitat is not involved, then the FWS is not too concerned. Point made that longleaf management is a fire dependent ecosystem and may violate the Clean Water Act. FWS requested that forest industry work more closely with them on ecosystem management. Wetlands maps are a planning tool, they are not a jurisdictional map. Use the maps like a screening document. To be used as a large scale planning tool. The NWI maps aren't to be used for very small wetlands.

Comment made that until folks are paid for biodiversity (ie - cost sharing), they may not be interested.

The SCS is still very much Farm Bill driven. Who determines reference sites? Concerned with lumping all wetlands within four systems/classifications, because there are vast differences in soils within wetlands. SCS needs to be a player in this process, we have a lot of soils expertise. SCS doors are open for interagency and industry cooperation.

Comment - Reference systems must be picked very carefully and done by interdisciplinary teams.

Mentioned that the FS is available to be a player in this process also. Discussed the human dimension of ecosystem management. FS is available to help set standards for riparian management. The National Forests could be used as a model in this process.

The NC State Forest Service stated that he hadn't gotten much from this meeting to carry back to NC forested wetlands landowners. He can mention the development of the HGM model, although it may be very costly to implement. NC state foresters today avoid discussions of minor drainage, too much uncertainty. That uncertainty when applied to management may be more costly and result of a less diverse crop in trying to avoid the minor drainage issue. If a big issue is involved, then the COE is approached. Wetlands BMPs are in good shape in NC. Urged extreme caution in the application of minor drainage. Wetlands BMPs address water management, but not specific about minor drainage. The design and application of drainage systems is not addressed. SC BMPs state that excess surface water be removed to aid in regeneration.

Comment - BMPs are really minimum standards to comply with the CWA. Minor versus major drainage couldn't be differentiated to address the issue in Alabama BMPs.

GA Forestry Commission comments - All pine plantations are classed as wetlands losses. Continuous training of state personnel needed to stay abreast of federal and state regulations and to adequately advise private landowners. Contradictory language in all the state and federal regulations. Private landowners more apt to go with pine management versus hardwood management because of the long time frame involved with hardwood management. All GA registered foresters must follow state BMPs and are held accountable for that. GA BMPs are designed to deal with water quality.

COE has a concern with what to do with spoil material arising from minor drainage operations. New BMPs must address the ditch itself and what to do with the spoils. Suggested that industry map

jurisdictional wetlands on their land to know where the "line" is. Can be done on GIS systems. "Have we reduced the reach of waters" is a core question. Suggested that forest industry put wetlands lines on their deed maps. Forest Industry Comment - Costs involved with this are prohibitive to industry, GIS maps are not accepted by the COE at this time. Not feasible until the COE accepts GIS maps. Jurisdictional levels are only good from the COE for three years and not for the rotation age. Suggested that a COE Regional Permit may be a possible answer to resolve the minor drainage issue on a COE district basis. Forest industry would loose a certain amount of flexibility in this situation. Suggested that industry come to the COE requesting a regional or general permit. Raises the issue of "permitting" an exempt activity. A NWP or GP would solve a lot of our current controversy. A NWP may be difficult to obtain. The state forester in Delaware is working on a GP for stewardship plans involving the wildlife component. The wish is to use GPs to cover wildlife activities within a silvicultural operation. An advantage of a GP or a NWP is for private landowners, not so clear-cut for industry.

--- End ---

WATER MANAGEMENT IN FORESTED WETLANDS WORKSHOP

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AGENDA

WATER MANAGEMENT IN FORESTED WETLANDS WORKSHOP

APRIL 26 - 28, 1994 --- Lenox Inn, Atlanta, GA

SPONSORED BY: USDA/Forest Service, Southern Region and Environmental Protection Agency, Region IV

WORKSHOP OBJECTIVE & GOALS:

To facilitate a process in which representatives of the public and private forestry sectors will provide input on technical aspects of minor forest drainage employed for the purpose of harvesting, regenerating, and managing forested wetlands, including operational requirements and environmental effects. Results of the workshop will help EPA in understanding what is considered minor drainage under the 404(f) exemptions.

In addition, results of the workshop may assist the states in reviewing their BMP's for water management on forested wetlands. To assemble information from knowledgeable forestry technical specialists from academia, government, and industry that describes drainage practices used in normal silvicultural operations among a variety of Forest owners.

Tuesday, April 26, 1994

08:00 Introduction & Opening Remarks: EPA and USFS personnel.

Tom Welborn, EPA, Atlanta
Bruce Bayle, USFS, Atlanta
Michael Goggin, Atlanta
Michael McGee, Atlanta

MORNING SESSION: SOILS - What is the state-of-the-art?:

08:30 DeWayne Williams, SCS - Soil Surveys and Classification

09:15 Dr. Thomas Fox, Rayonier - Decision Making in Forest Mgmt.

10:00 Break

10:30 Dr. Michael Aust, VPI - Harvesting Considerations/Site Protection.

11:15 Soils Panel:
Moderator - James Robinson, SCS, Ft. Worth, TX
o Dr. Robert M. Shaffer, VPI, Blacksburg, VA

o Jack Hill, USFS & EPA/Region III, Dallas, TX

11:40 Question and Answer Session

12:00 Lunch

AFTERNOON SESSION: HYDROLOGY/MODELING:

1:00 Dr. Mark Brinson, ECU and Dr. Wade Nutter, Univ. of GA - Geomorphologic Aspects of Forested Wetlands.

2:00 Dr. Wayne Skaggs, NCSU - Water Management Modeling.

2:30 Break

3:00 Dr. Carl Trettin, Oak Ridge Natl. Lab. - Water Management in the Lake States.

3:30 Dr. Tom Williams, Clemson Univ. - Water Quality. (unable to attend, his paper was presented for the Proceedings)

4:00 Hydrology/Modeling Panel:
o Moderator - Dr. Tim Adams, Columbia, SC
o Dr. Warren Harper, USFS, Wash., DC
o John Dorney, NC Div. of Envir. Management, Raleigh, NC
o Donald E. Woodward, SCS, Wash., DC

4:30 Question and Answer Session

5:00 Adjourn

Wednesday, April 27, 1994

MORNING SESSION: SILVICULTURAL APPLICATIONS:

8:00 Dr. Paul Lilly, NC Agricultural Extension Service. - Historical Perspective.

8:40 Dr. Robert Kellison, NCSU - Hardwood Management and Drainage.

9:20 Dr. Bill McKee, USFS - Tree Growth and Site Productivity.

10:00 Break

10:30 Dr. Bryce Stokes, USFS and Dr. Robert Rummer, USFS -

Wetlands access/Transportation.

11:10 Silvicultural Applications Panel:
Moderator - Stan Adams, NC Forest Service, Raleigh, NC
o Dr. John Stanturf, USFS, Stoneville, MS
o George Henderson, E. Coast Forest Products, Roper, NC

11:30 Question and Answer Session

12:00 Lunch

AFTERNOON SESSION: PRACTICAL APPLICATIONS AND USES:

Case studies:

1:00 Bob Fledderman - Westvaco Corp.

1:40 Bart Sabine, Consulting Forester, SC

2:20 Break

3:00 Dr. Lyndon Lee, Consultant, Seattle, WA

3:40 Practical Applications Panel:
Moderator - Dr. Donal Hook, Clemson Univ., Clemson, SC
o Jim Allen, FWS, LaFayette, LA
o Dr. J. W. Gilliam, NCSU, Raleigh, NC

4:15 Question and Answer Session

4:45 Adjourn

Thursday, April 28, 1994

8:00 Wrap-up Session

10:00 Break

10:30 Continue with wrap-up

12:00 Adjourn